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GROUND WATER QUALITY FLUCTUATIONS

- A PILOT STUDY -

WATER RESOURCES PAPER 11

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- A PILOT STUDY -

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ABSTRACT

Ground-water quality samples were obtained at regular intervals from 10 domestic water wells over a 21-month period, and were analysed for the common inorganic chemical constituents present in the natural hydrogeological environment. The purpose of the sampling study was firstly to determine the degree of fluctuation over time in each ground-water quality parameter, and secondly to provide sampling frequency input data for the planning of a permanent ground-water quality monitoring network in Ontario.

Parameter fluctuation was assessed with respect to the different types of aquifers or water-bearing formations found in southern Ontario, and with respect to the different depths and types of water wells common to the province. Wells varied in depth from 13 feet to 228 feet below ground level, with eight wells obtaining water from overburden aquifers and two from bedrock aquifers. Four wells located in the same area but obtaining water from different aquifers were also included to determine if correlations in water quality were apparent in different formations at the same location.

Data analyses using the coefficient of variation were valuable in assessing the relative degree of variability of each study parameter and of each well. The parameters total iron and total nitrate were found to be the most variable, whereas hardness, alkalinity and pH were the least variable. Seasonal variability was found in some cases for nitrate and chloride. Random variability was found in total iron and to a certain extent in specific conductance. Wells obtaining water from confined aquifers showed a lesser degree of variability in water quality than wells obtaining water from leaky or unconfined aquifers. Sampling frequency in a water-well network setting was established at one or two samples per year for most parameters with the exception of iron and nitrate, which would require more frequent sampling in order to adequately assess the concentrations.

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METRIC CONVERSION FACTORS

1 foot	=	0.305 metres
1 inch	=	2.54 centimetres
1 mile	=	1.61 kilometres
1 gallon	=	4.54 litres

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- A PILOT STUDY -

1. INTRODUCTION

In consideration of the present-day interest in the protection and preservation of Ontario's ground-water resources from irrepairable damage by pollutants, a pilot study was carried out to determine fluctuations in natural ground-water quality in southern Ontario in order to provide data for the design of a Provincial ground-water quality network. Ten domestic water wells representative of different hydrogeological conditions were selected to act as sampling sites; the parameters for study included the common inorganic chemical constituents that are normally present in the natural hydrogeological environment.

The degree of dissolved constituents in ground water depends on a combination of many factors. The initial input into ground water depends primarily on precipitation, spring thaw events and flooding. Atmospheric conditions affecting the pH of precipitation also can have a bearing on ground-water chemical constituents. As soon as ground water enters the subsurface, it dissolves minerals in its path and a chemical equilibrium is approached with the mineral constituents of the surrounding geological formations. Other factors affecting the general chemical composition of ground water include the permeability of the host formation, the temperature of the ground water, the degree of solubility of the minerals comprising the formation, the length of contact time of the water within the formation, the pressure within the formation, and the degree of microbiological activity within the formation.

In general, formations at great depths will contain waters that are hundreds or thousands of years old, and which will usually be high in dissolved solids. Such waters may be unsuitable for domestic use, and may even prove objectionable for agricultural or industrial uses. Waters in shallower formations will generally be younger in age, will contain less dissolved solids, and will generally be more suitable for use and consumption by man.

Since most ground water is obtained from wells, the method of construction, the site location and depth of completion of a well are significant in relation to the quality of the water obtained from a well. The well construction method (i.e., bored or drilled) quite often determines the depth and type of water-bearing formation (aquifer) into which a well can be completed. For instance, dug or bored wells are often limited in depth to shallow water-bearing formations, and will penetrate only a short distance within the saturated zone below the water table. Water is often obtained in limited amounts under these conditions. Conversely, drilled wells can tap deeper water-bearing formations, which often contain ground water under pressure and in larger amounts. The site location of a well is also a factor affecting ground-water quality, especially on properties where potential pollution sources exist (e.g., septic tile beds, barnyards, agricultural areas, underground storage tanks, road-salt runoff).

A final factor significant in the ground-water quality of a particular well is the pumping and distribution system itself. The alteration of certain water-quality constituents (i.e., iron or pH) can take place as soon as the water leaves an aquifer and enters a well. Factors effecting these changes include a decrease in pressure and an increase in temperature. Further changes in temperature and pressure are influenced by the well pump, storage tank and plumbing system, especially if these are enclosed in above-grade or heated areas. In certain cases, these changes may result in objectionable water quality for domestic and other uses. Knowledge of the ways that these changes can be brought about by the pumping and distribution systems is essential to the final interpretation of ground-water analyses results.

2. SCOPE AND OBJECTIVES OF THE STUDY

The primary objective of this pilot study is to establish what changes or variability with time can be expected in natural ground-water quality in different hydrogeological environments, in order to provide data for the planning of a ground-water quality monitoring network in Ontario. For network planning purposes, the most important data required relate to the optimum sampling frequency for each parameter, in order to achieve an economical, yet comprehensive network. The present report documents ground-water quality changes, without presenting the in-depth reasons for such changes.

In the selection of suitable wells for the study, the aim was to choose wells in as many hydrogeological environments as possible. Three of the selected wells are in shallow water-table aquifers in overburden, five wells are completed in confined overburden aquifers and the remaining two wells are in bedrock aquifers. At one site, four wells are located within 1/2 mile of each other, and are at depths varying from 22 feet to 228 feet below ground level. The close proximity of these four wells allows a comparison of water qualities and their variations in different water-bearing formations in the same area. In order to round out the types of ground water included in the study, a well with very high concentrations of natural sulphate and hardness was included to contrast with the other wells which yield essentially more potable water. The data in this report cover a period of 21 months from April 1979 to December 1980.

3. SAMPLING AND ANALYSIS CRITERIA

The parameters chosen for routine analysis are the naturally-occurring inorganic chemical constituents and index parameters most often measured in the assessment of well water for domestic and other consumptive uses. These parameters consist of the major anions and cations (sodium, potassium, calcium, magnesium, iron, bicarbonate, chloride, sulphate, nitrate) and other index parameters, including hardness, pH and specific conductance. The normal analyses were augmented with a special set of samples in February 1980, which were analysed for trace metals and other parameters often used for the detection of ground-water contaminant sources*.

Sampling was initiated in April 1979, and was carried out on a weekly basis for the first five months, at which time the sampling frequency was reduced to once every two weeks. In June 1980, sampling was further reduced to once per month.

In most cases the samples were obtained from normal household taps; however, if a system was equipped with a treatment device such as a water softener or an iron filtration unit, the sample was obtained from a tap located between the pressure tank and the treatment device. In one case, samples were obtained from a dug well equipped with a hand pump. Currently recommended Ministry of the Environment sampling procedures were used in all cases. Water samples were analysed at the Ministry of the Environment laboratories in Toronto and London, Ontario.

All analyses results were subjected to a routine cation-anion balance program to check on gross errors. The results were plotted as they became available to further check on anomalies, and were subsequently stored on computer disk to facilitate statistical analyses.

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* Samples were analysed for the following parameters: Se, As, SiO_2, CN, Mn, Cu, Zn, Ba, Cd, Cr, Pb, Ag, F, DOC, MBAS and the N cycle.

4. SITE DESCRIPTIONS

4.1 Introduction

Each well site is numbered in order from west to east, as shown on Figure 4.1. The site descriptions are presented in the following section, with the overburden wells discussed first, followed by the bedrock wells. A summary of the important physical characteristics of each well is shown in Table No. 4.1.

4.2 Wells in Overburden

Well No. 1

Well No. 1 is located in the physiographic region known as the Caradoc Sand Plain, (Chapman & Putnam, 1966) a rural agricultural area where corn and small grain crops predominate. It is a bored well 13 feet deep and is totally in sand. It is cased with 30-inch diameter concrete culvert tiles, and the water level was 7.4 feet below ground level on August 8, 1979. The well is approximately 30 years old, and is about 50 feet away from an abandoned barn. The property on which the well is located is surrounded on three sides by corn fields, which were reported to be fertilized yearly in the spring.

Well No. 3

Well No. 3 is located in the Galt Moraine physiographic region, an end-moraine feature comprised of stony till. The well is situated on the edge of a small village in a newly-developed area. Corn is the predominant crop in the surrounding agricultural area. The six-inch diameter well was constructed in 1976 to a depth of 100 feet, and is completed in a five-foot layer of gravel. The driller's log is as follows:

brown stony clay	- 0 to 15 feet
grey sandy clay	- 15 to 95 feet
grey gravel	- 95 to 100 feet

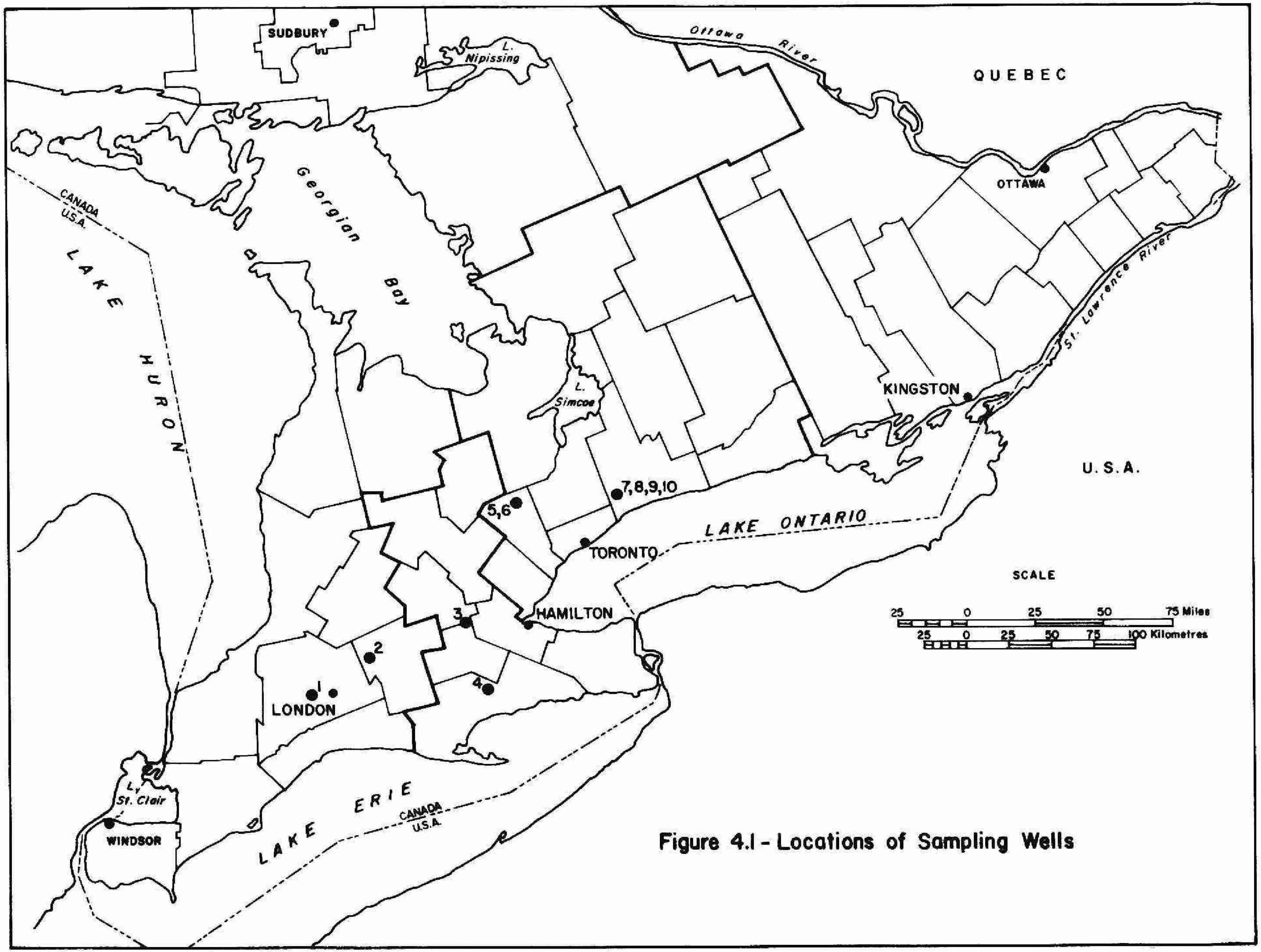


Figure 4.1 - Locations of Sampling Wells

Table 4.1
Pilot Study Water-Well Characteristics

Well No.	Type	Age (years) (as of 1982)	Aquifer	Depth (feet)
1	bored	30 $\pm$	sand	13
2	drilled	7	limestone	165
3	drilled	6	gravel	100
4	drilled	8	gravel	30
5	drilled	10	sand	115
6	dug	100+	unknown	38
7	drilled	15	sand	177
8	drilled	20	shale	228
9	drilled	25	sand & clay	71
10	dug	old	unknown	22

Well No. 4

Well No. 4 is located in the physiographic region known as the Haldimand Clay Plain, a plain of low relief consisting mainly of clay. This well, which was included in the pilot study specifically because of its high concentrations of sulphate and hardness, is located just northeast of the Onondaga Escarpment, a bedrock outcrop of low relief. The underlying bedrock is the Bertie Formation (dolomite); however, the Salina Formation (dolomite, shale and gypsum), further to the north, is considered to be the source of much of the sulphate in ground water in the area.

The well is situated on the edge of a small village in a residential housing subdivision. The six-inch diameter well was constructed in 1974 to a depth of 30 feet into a gravel aquifer, which likely rests on, and is hydraulically connected to, the underlying bedrock. The driller's log is as follows:

topsoil	-	0 to 4 feet
brown clay	-	4 to 20 feet
blue clay	-	20 to 29 feet
grey gravel	-	29 to 30 feet

At the time of construction, the well flowed at 10 gallons per minute. It stops flowing each year from mid-July to the end of September.

Well No. 5

Well No. 5 is located in the physiographic region known as the Oak Ridges Moraine, a kame moraine of sands and gravels overlain by till. The area is marked with many small hills and depressions. The well is situated approximately 1 1/2 miles east of the Niagara Escarpment, the face of which in this area is buried by thick kame deposits typical of the Oak Ridges Moraine. The well is in a rural area where the predominant farming activities consist of some small grains and a high proportion of pasture.

The well was constructed in 1972 to a depth of 115 feet into fine grey sand. The driller's log is as follows:

soft grey silt and clay	- 0 to 85 feet
soft brown silty sand	- 85 to 104 feet
soft brown medium sand	- 104 to 109 feet
soft grey fine sand	- 109 to 115 feet

Well No. 6

Well No. 6 is located approximately 300 feet east of Well No. 5. This well is hand-dug, is 36 inches in diameter and is 38 feet deep. No log is available for this well.

Well No. 7

Well No. 7 is located in the physiographic region designated as the South Slope Till Plain. This is a continuation of the southern flank of the Oak Ridges Moraine, and is a gently sloping till plain that is drumlinized in scattered locations. The till is classified as the Halton Till, having a silty texture, and is overlain in a few areas by kame and glaciolacustrine deposits. The underlying bedrock consists of grey shale of the Whitby Formation. Well No. 7 was drilled in 1967 to a depth of 177 feet, and is completed into a layer of sand. The well casing is five inches in diameter. The driller's log is as follows:

dug well	- 0 to 45 feet
clay and boulders	- 45 to 90 feet
clay and stones	- 90 to 174 feet
water-bearing sand	- 174 to 177 feet

Well No. 9

Well No. 9 is located about 1000 feet northeast of Well No. 7 and the same geologic and physiographic descriptions apply. The well was constructed in 1957 to a depth of 71 feet into a water-bearing formation of sand and blue clay. The well is cased with four-inch diameter casing, and its yield was originally rated at 1 1/2 gallons

per minute. Located underneath the side porch, the well is constructed through the bottom of an old dug well which formerly supplied the house. The property is situated in a small village on an unpaved side street. The driller's log is as follows:

dug well	-	0 to 26 feet
sand and clay	-	26 to 39 feet
blue clay and sand	-	39 to 69 feet
sand and blue clay	-	69 to 71 feet

Well No. 10

This well is an old hand-dug well, 22 feet deep. It is located about 300 feet east of Well No. 9. The gravel road fronting the property is about 30 feet from the well. An old hand pump sits on top of the well. In this case, samples were taken directly from the hand pump instead of the domestic pressure system. No log exists for this well.

4.3 Wells in Bedrock

Well No. 2

Well No. 2 is located in the physiographic region known as the Oxford Till Plain, on the upper edge of a deep river valley. It is located in a rural agricultural area and pasture and hay crops are found in the immediate vicinity. The six-inch diameter well was constructed in 1975 to a depth of 165 feet and it is completed in limestone bedrock (Dundee Formation). The driller's log is as follows:

brown clay and stones	-	0 to 17 feet
blue clay and stones	-	17 to 50 feet
grey gritty hardpan and stones	-	50 to 100 feet
brown limestone rock	-	100 to 165 feet

Well No. 8

This well is located approximately 1000 feet northwest of Well No. 7, on the southern flank of the Oak Ridges Moraine. In this area the moraine consists of the Halton Till, a silty till overlain in a few areas by kame and glaciolacustrine deposits. Well No. 8 was drilled in 1962 to a depth of 228 feet, ending in shale bedrock (Whitby Formation). The pumping system is installed directly above the top of the well in an underground pit; the top of the casing is not fitted with a sanitary waterproof seal. The underground pit is part of a previously-dug water-supply system. The driller's log is as follows:

dug well	-	0 to 25 feet
clay and stones	-	25 to 76 feet
boulders	-	76 to 83 feet
sandy clay	-	83 to 125 feet
quicksand	-	125 to 180 feet
sandy clay	-	180 to 200 feet
blue shale rock	-	200 to 228 feet

5. WATER QUALITY FLUCTUATIONS

5.1 Introduction

The results of the study are presented firstly in graphical format for each individual well, to show any seasonal changes in water quality concentrations. Secondly, the results for each parameter are presented and analysed using basic statistical methods.

Appendix A contains graphs showing water quality parameter fluctuations with time for each well. The statistical summaries of Appendix B show the minimum, maximum, mean, range, standard deviation, coefficient of variation (CV) and number of analyses for each parameter in each well. Appendix C shows plots of the maximums, minimums and means, together with the coefficients of variation for most of the parameters for which analyses were carried out. Magnesium, potassium and fluoride, which did not have sufficient data entries to warrant plotting, were not included in Appendix C.

The standard deviation and the coefficient of variation are statistical expressions used to indicate dispersion or variation relative to the mean. The standard deviation for each parameter was calculated using an SPSS computer program package (Nie et al., 1975), and can be expressed as a measure of the variability of a set of data about the mean. The larger the standard deviation, the greater is the variability of the set of data. The coefficient of variation is defined as the standard deviation divided by the sample mean, expressed as a percentage. Since it is dimensionless, it is useful in comparing distributions where units and magnitudes differ. However, a word of caution should be offered concerning the coefficient of variation. For data sets in which the mean approaches zero, the coefficient of variation will be very large, and conversely, for data sets in which the mean is very large with respect to the standard deviation, the resultant coefficient of variation will be small. In addition, given two data sets with the

same range, a high-valued anomaly in a data set will yield a strikingly high value for the coefficient of variation as compared to a data set with a low-valued anomaly.

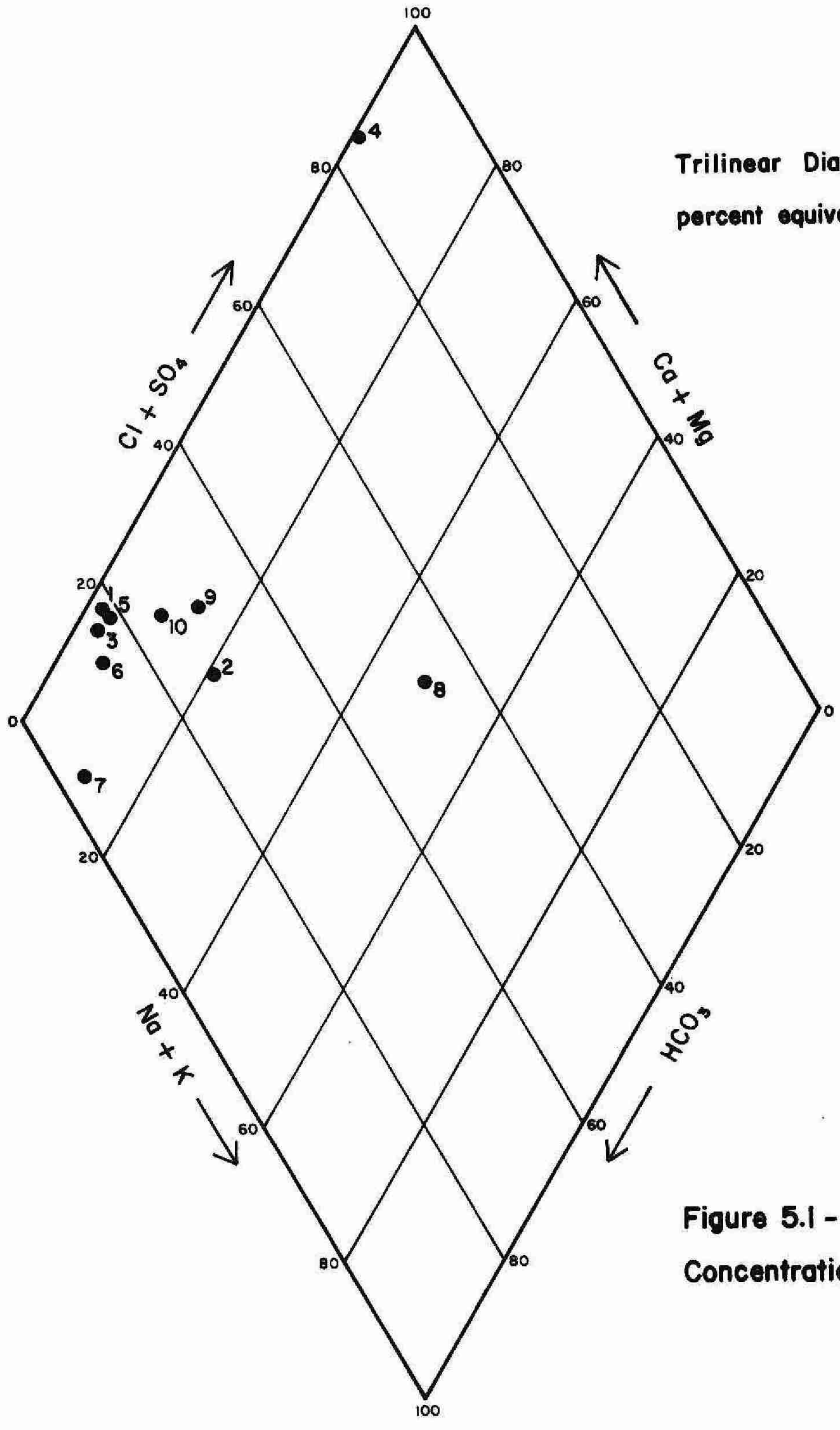
The trilinear diagram shown in Figure 5.1 illustrates the distribution of the major ions for each of the 10 wells. Eight of the wells show a predominance of calcium-bicarbonate. The positions of the other two wells, No. 4 and No. 8, reflect their high sulphate and chloride concentrations, respectively. These wells yield characteristic ground waters from the Salina Formation (dolomite, shale and gypsum) and the Whitby Formation (shale), respectively.

In Tables 5.1 and 5.2, a summarized expression of all the data obtained in the study is presented. In Table 5.1 the water wells included in the study are ranked according to water quality variability, as shown by the mean of the calculated coefficients of variation for all parameters for each well. In this way, the wells showing the highest coefficients of variation are identified as the most variable in the study. Similarly, Table 5.2 summarizes the data for the major study parameters by showing the mean of the coefficients of variation for all wells by parameter. A simple ranking is thereby achieved, from the most variable parameter to the least variable.

5.2 Wells in Overburden

Well No. 1

The water quality plot for Well No. 1 is shown in Figure A.1, Appendix A. Most notable are the high nitrate values, approaching, and exceeding in one case, the Ministry of Environment's potable water quality criteria of 10 mg/L. The lowest nitrate levels were detected during the late summer and early fall months; the highest values were found in the winter and spring periods. Specific conductance fluctuated in the same pattern as nitrate, although to a lesser degree. Hardness, alkalinity, and sulphate showed minor fluctuations. Chloride showed a slightly increasing trend, but sodium was uniform throughout. Iron was detected at low levels.



Trilinear Diagram - All values in percent equivalents per million

Figure 5.1 - Major Ion Concentrations of Ground Water

Table 5.1

Means of Coefficients of Variation and Variability Rankings
For Parameters by Well*

Rank	Well No.	Mean Coeff. of Variation	Variability
1	9	34.4	most variable
2	5	24.0	
3	4	20.9	
4	10	20.5	
5	6	18.7	
6	8	15.9	
7	2	15.9	
8	1	12.9	
9	7	12.1	
10	3	9.5	least variable

* mean CV calculated by averaging the coefficients of variation for the 10 major parameters by well.

The high nitrates may be derived from fertilizer that is applied to the adjacent corn fields. The sand overburden in the area could be allowing the nitrates to move readily into the well.

Well No. 3

The water quality plots for Well No. 3 are shown in Figure A.3, Appendix A. The variability of iron is readily visible; all the other parameters showed relatively little variation with time. By averaging the coefficients of variation for all parameters for each well, Well No. 3 was calculated to be the least variable of the 10 study wells (Table 5.1).

Well No. 4

The water quality plots for Well No. 4 are shown in Figure A.4, Appendix A. This ground water is very high in hardness, sulphate and specific conductance, and requires treatment prior to domestic use, with a softener and an iron filtration unit. Data from August to mid-November 1979 were not used in the analysis because of a plumbing system malfunction; the remaining data indicated that most chemical parameters showed no discernable trends throughout the period of acceptable samples.

Results for total iron for Well No. 4 showed uniform concentrations throughout most of the year, but a dramatic increase was seen in the summer and fall of 1980. A bacteriological sample was obtained on November 9, 1979 and the results revealed the presence of iron oxidizing bacteria of the genus Gallionella. The explanation for the seasonal increase in iron is linked to the fact that the well flows for most of the year except for the late summer and fall. The presence of air in the casing during the non-flowing period provides good growing conditions for this type of bacteria, which thrives under aerobic conditions, during which time the total iron readings concurrently increase. After flowing conditions are re-established in the well, anaerobic conditions check the growth of the bacteria, and the flushing action of the continuous flow keeps the iron concentrations to a minimum (Smith, S., 1980; Cullimore, D.R., and McCann, A., 1979; McKee, J.E., and Wolf, H.W., 1963).

Well No. 5

The water quality plots for Well No. 5 are shown in Figure A.5, Appendix A. Slight water quality changes appeared in this well for hardness, alkalinity, specific conductance, chloride and nitrate. In all cases the peak concentrations occurred in November or early December, and the lowest concentrations in the spring or early summer. The seasonally-related fluctuations in these parameters cannot be explained at this time. Total iron was observed to fluctuate randomly throughout the sampling period. On three occasions in 1980, the Ministry's desirable criteria of 0.3 mg/L were exceeded.

Well No. 6

The water quality plots for Well No. 6 are shown in Figure A.6, Appendix A. This well showed some changes in alkalinity and chloride; however, these changes did not follow the same seasonal patterns found in neighbouring Well No. 5, signifying that wells in close proximity will not necessarily demonstrate similar water quality characteristics.

Water quality changes appeared to be more pronounced in 1979 than in 1980. Specifically, alkalinity and chloride showed definite peaks in July and May 1979, respectively. Iron concentrations showed random fluctuations typical for most wells in the survey.

Well No. 7

Well No. 7 water quality plots are illustrated in Figure A.7, Appendix A. All parameters, except iron, were consistent throughout the sampling period. Iron levels were found to be higher than the desirable criteria, and showed the variability usually associated with this parameter.

Well No. 9

Well No. 9 plots are shown in Figures A.9a and A.9b, Appendix A. Seasonal changes are apparent in most parameters; hardness and alkalinity showed their lowest values in the fall. Sodium, chloride, and sulphate showed peaks in the summer, and low values in the winter and spring. Nitrate was fairly scattered, but tended to show higher values in the winter and spring months; iron demonstrates a random variability. Well No. 9 demonstrated the highest variability of all wells in the pilot study, as substantiated by the mean of the coefficients of variation (Table 5.1).

A number of observed potential pollutant sources in the immediate vicinity of Well No. 9 could be contributing to the water quality variability. These pollutant sources include an abandoned in-ground fuel storage tank and an old septic tank system.

Well No. 10

Well No. 10 water quality plots are shown in Figure A.10a and A.10b, Appendix A. Variability was noted in a few of the parameters. Nitrate showed higher values in the fall, and lower values during the spring months; chloride and sodium showed similar changes. Since the well is a shallow dug well, these three parameters could be related to the entry of surface pollutants from septic tank and other external sources.

High values for iron are also shown in the water quality plots. The fluctuations were wide-ranging, similar to other wells in the survey. Since the sampling in this case was directly from the hand pump on top of the well, this might signify that iron accumulation occurs in the well and/or pump.

5.3 Wells in Bedrock

Well No. 2

The water quality plots for Well No. 2 are shown in Figure A.2, Appendix A. For the most part, all parameters remained relatively steady throughout the monitoring period, with the exception of iron and sulphate, which fluctuated at random.

Well No. 8

Well No. 8 water quality plots are shown in Figure A.8, Appendix A. Sodium and chloride were detected at higher levels than in the other wells sampled, reflecting the shale bedrock water source. Chloride (and associated specific conductance) showed considerable variability throughout the sampling period, although it appears to be random and not seasonal. Iron also showed random variability.

5.4 Parameters

Sodium

The largest ranges for sodium were found in wells No. 2, No. 8 and No. 9, and the highest readings were between 75 and 105 mg/L, as recorded in Well No. 8 (Figure C.1, Appendix C). The range for sodium was greatest in those wells which showed the highest concentrations; however, the coefficient of variation did not follow a similar relation. This fact exists because the percentage of variation of the standard deviation to the mean is not necessarily dependent on the absolute magnitude of the range. As shown in Table 5.2, the mean CV for sodium ranked fifth for the 10 major study parameters, which would place it as a moderately variable parameter.

Calcium

As shown in Figure C.2, most of the sample results for calcium varied from 50 to 150 mg/L, with the exception of Well No. 4, which showed concentrations between 548 and 625 mg/L. The coefficients of variation showed no extremes relating to the mean, maximum and

Table 5.2

Means of Coefficients of Variation and Variability Rankings for All Wells by Parameter*

Rank	Parameter	Mean Coeff. of Variation	Variability
1	Fe	69.5	most variable
2	NO_3	42.1	
3	Cl	24.2	
4	SO_4	23.9	
5	Na	14.7	
6	Ca	8.6	
7	Sp. Cond.	4.2	
8	Hardness	3.9	
9	Alkalinity	3.8	
10	pH	2.2	least variable

* mean CV calculated by averaging the coefficients of variation for all wells by parameter

minimum concentrations. The mean CV for calcium (Table 5.2) gives calcium a variability ranking of sixth overall, placing it as moderately low in variability with respect to the other study parameters.

Alkalinity

The overall minimum and maximum concentrations for alkalinity were 172 and 348 mg/L, respectively (Figure C.3). Considering the wide variation of concentrations in most other study parameters, (e.g., hardness, chloride, sulphate) alkalinity showed remarkably similar levels of concentration for all 10 study wells. Well No. 9 showed a CV that was higher than the others, which supports the seasonal fluctuation found in this well. Overall, alkalinity showed uniformly low variability, and was ranked as ninth in variability (Table 5.2).

Hardness

Hardness results varied between 189 and 419 mg/L (Figure C.4) for nine of the study wells. The tenth well (Well No. 4) showed high values of hardness varying from 1488 to 1628 mg/L. The coefficients of variation were consistently very low, regardless of concentration. Table 5.2 ranks hardness as eighth overall, signifying low variability.

Chloride

The largest ranges for chloride were found in wells No. 8, No. 9 and No. 10, with Well No. 8 showing the highest readings between 158 and 195 mg/L (Figure C.5). Wells No. 1 to No. 7 showed concentrations which were all below 24 mg/L. Figure C.5 shows that Well No. 8 had the lowest CV although its chloride concentrations were considerably higher than the other wells. The CV's showed a large amount of variability amongst themselves, with a maximum CV of 51.6 and a minimum of 5.0, signifying a moderately high degree of variability for this parameter. Table 5.2 ranks chloride as the third most variable parameter overall.

Sulphate

The sulphate range and levels were very high in Well No. 4, and moderately low in the other nine wells (Figure C.6). The coefficient of variation was high in Well No. 8, but this was due to an anomalously high value in the data. Wells No. 7 and No. 9 showed moderate CV's although the significance of the CV for Well No. 7 remains inconsequential since the level and range of concentration are very small. Well No. 9 is the only well in which the CV is of importance, reflecting the pronounced seasonal fluctuation of sulphate in this well. Sulphate ranked fourth in variability, as shown in Table 5.2, signifying that this parameter is moderately variable with respect to the others.

Nitrate

Wells showing the largest ranges in nitrate also demonstrated the highest levels (Figure C.7). Three wells showed virtually no presence of nitrate, (No. 3, No. 7 and No. 8) whereas two wells were occasionally in excess of the guideline of 10 mg/L (No. 1 and No. 9). Well No. 2 showed the highest coefficient of variation; however, one high value in the data was responsible for the large coefficient. Well No. 9 showed the widest range and the second largest CV, reflecting a large dispersion of nitrate values about the mean. Table 5.2 shows that nitrate is the second ranking water quality constituent for variability. The above findings signify that nitrate, when detected in a well, can be highly variable.

Iron

Total iron showed results that were different from all other parameters in the study. Only one well showed iron in trace amounts; the other nine showed detectable iron levels, with six wells averaging higher than the accepted criterion of 0.3 mg/L (Figure C.8). In examining the statistical data for iron, most of the wells showed arithmetic means that were at the low end within their respective ranges, signifying that much higher concentrations of iron occasionally were present in a few of the analyses.

Accordingly, iron showed the highest mean coefficient of variation of any parameter analysed in the study. Table 5.2 demonstrates that total iron was ranked as the most variable water quality parameter.

In one well, the nuisance bacteria Gallionella was confirmed, which resulted in abnormally high iron concentrations on a seasonal basis in late summer and fall. The other wells in the study showed wide fluctuations in iron concentrations at random intervals. This was attributed to the oxidation of ferrous iron to the insoluble ferric state, either in the plumbing system, pressure tank or in the well itself, with the subsequent collection of iron precipitate in the pressure tank reservoir. The difficulty in completely flushing pressure systems prior to the taking of water samples resulted in random variations in the concentrations of this parameter.

Lab pH

Lab pH showed the lowest variability of any parameter. Most pH values were between 7 and 8, with the widest ranging well (No. 10) showing a minimum of 6.1 and a maximum of 8.1 (Figure C.9). As shown in Table 5.2, pH is ranked as the least variable parameter in the study.

Specific Conductance

The overall minimum and maximum concentrations for specific conductance were 352 and 2230 mmhos/cm, respectively. Figure C.10 shows that the ranges and magnitudes of specific conductance for all study wells were quite dissimilar; however, the CV's for all wells were uniformly low indicating little dispersion of values relative to the mean value for each well. Table 5.2 ranks specific conductance as the seventh parameter, indicating low variability.

Potassium

One well included in the study (No. 6) showed a slight peak in potassium values in July 1979. Potassium was detected usually at very low levels in most wells and has not been plotted on the water quality graphs or included in the analysis of variability.

Trace Metals and Pollutant Indicators

Analyses for trace metals and some of the common pollutant indicators are shown in Appendix D. One sampling run was carried out on each well during February or March 1980, to augment the common inorganic parameters that were sampled regularly and to give a fuller spectrum of water quality parameters.

Those results which are equal to or higher than the Ministry of the Environment's recommended drinking water quality criteria are underscored in Appendix D. Parameters which do show levels equal to or exceeding the criteria include manganese, barium, cadmium, fluoride and free ammonia. Of note are the manganese level in Well No. 8 and the cadmium level in Well No. 10, as these two concentrations are well above the Ministry criteria. Also of note is the fact that wells No. 7 to No. 10, which are in relatively close proximity, showed detectable levels of cadmium.

6. SUMMARY AND CONCLUSIONS

The data obtained through this study indicate that certain ground-water quality parameters show seasonal and random fluctuations, some associated with natural conditions while others may be functions of well construction, surface pollutant sources, and/or plumbing system effects.

In assessing the 10 study wells, there is no distinction in variability between the bedrock and overburden wells. The two bedrock wells were ranked sixth and seventh in variability, and showed no tendencies in variability that were not also evident in the overburden wells in the study.

Those wells which were purposely selected in close proximity to each other did not show many common characteristics in variability. In the case of wells No. 5 and No. 6, no similarity existed in the fluctuation of parameters. In the case of wells No. 7 to No. 10, a few parameters showed fluctuations. In particular, wells No. 9 and No. 10 showed distinct changes in nitrate, sodium and chloride; however, the fluctuations were not coincident. The only common characteristic that wells No. 7 to No. 10 shared was the presence of cadmium in detectible concentrations. The source of cadmium in wells No. 7 to No. 10 is not known at this time.

There was no correlation in degree of variability found in well depth (shallow vs. deep wells) or in well age (wells less than 10 years old vs. wells more than 10 years old). Nonetheless, it was concluded from the study data that wells obtaining water from confined aquifers showed a lesser degree of variability than wells obtaining water from unconfined and leaky aquifer conditions. This conclusion was drawn from the fact that four out of the five lowest ranking wells in variability are in confined aquifers (wells No. 2, No. 3, No. 7 and No. 8), whereas four out of the five highest ranking wells in variability are in unconfined or leaky aquifers (wells No. 5, No. 6, No. 9 and No. 10). The wells in unconfined or leaky aquifers tended to show more variability in the parameters

often related to near-surface pollutants such as those from septic tank effluent, agricultural fertilizers and road salting. These parameters include nitrate and chloride.

Variability in individual water quality parameters was found in differing magnitudes. In order of variability, the parameter values showed the following characteristics as dealt with in turn.

Iron was the most variable parameter, showing random variability in all cases. The exposure to oxygen either in the well itself or in the plumbing system contributes to the oxidation of ferrous iron to the insoluble ferric state. The subsequent collection of the iron precipitate in the well or plumbing system results in random concentrations of iron in water samples. In one case, the presence of the iron bacteria Gallionella resulted in a seasonal fluctuation in total iron.

Nitrate, the second most variable parameter, showed seasonal fluctuations in four wells, although these changes were not seasonally similar. Two of the wells showed spring peaks with late summer lows (wells No. 1 and No. 9); the other two wells showed spring lows and fall peaks (wells No. 5 and No. 10).

Chloride showed moderately high variability, and was found to fluctuate in four of the study wells. Seasonal peaks did not necessarily coincide, with one well peaking in the spring, one in the summer and two in the fall (wells No. 6, No. 9, No. 5 and No. 10, respectively). Chlorides in these four wells may have originated from surface contamination by road salt or from septic tank effluent. High levels of natural chloride associated with the shales of the Whitby Formation were found in Well No. 8; however, continuously random fluctuations were observed in this well, as opposed to the seasonally changing fluctuations observed in the aforementioned wells.

One well showed seasonal changes in sulphate whereas the other wells showed either random sulphate fluctuations or stable readings. Sulphate was classified as moderately variable with respect to the other parameters.

Slight seasonal changes for sodium were shown in wells No. 9 and No. 10, peaking in both wells in the early and late fall and falling to lows in the spring. No significant changes were apparent in the other wells. Sodium was classified as moderately variable with respect to the other parameters. Similarly, calcium showed moderate variability with respect to the other parameters.

Specific conductance showed seasonal variability in three cases, (wells No. 1, No. 9 and No. 10) showing a general correlation with chloride and nitrate fluctuations. In half the study wells, specific conductance fluctuated at random; it showed no fluctuations in two wells drilled into confined aquifers (wells No. 2 and No. 7). The degree of variability of specific conductance with respect to the other parameters was low.

Hardness showed low variability throughout the study, showing no fluctuations in nine of the wells. Seasonal fluctuation was noted in one well, (No. 9), where declines in the fall of 1979 and 1980 were evident. Likewise, alkalinity (bicarbonate) showed low overall variability in the study wells. Seasonal changes were evident in wells No. 9 and No. 10; Well No. 9 showed definite peaks in the spring and early summer, with lows in the fall; Well No. 10 showed lows in the fall and winter. The other wells showed no fluctuations in alkalinity.

The lowest variability of any parameter was shown by pH. No seasonal fluctuations were evident with this parameter.

In ground-water quality sampling, whether it be a single sample, a series of samples from the same source, or a series of samples from different sources, parameter variability must be considered. The parameters selected for any ground-water sampling program and the frequency of sampling will have a bearing on the interpretation of the analyses results. Specifically, random variability in the

results will be an inherent factor for such parameters as total iron and to a certain extent specific conductance. Seasonal variability is possible in some cases for nitrate and chloride. Of particular note are such parameters as alkalinity and hardness, which show very little variability with time, and total iron and nitrate, which show a high degree of variability with time.

In selecting an optimum sampling frequency for a long-term monitoring network for natural ground-water quality, it should be borne in mind that, with the exception of iron and nitrate, only one or two samples per year will be necessary to establish a good approximation of the background ground-water quality. However, when sampling for such parameters as iron and nitrate (and to a lesser extent chloride) samples will need to be obtained more often than once a year in order to evaluate the magnitude of fluctuations in these parameters.

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Appendix A

Graphs of Ground-Water Quality

N.B: Vertical scales for sulphate, nitrate and iron may differ among figures.

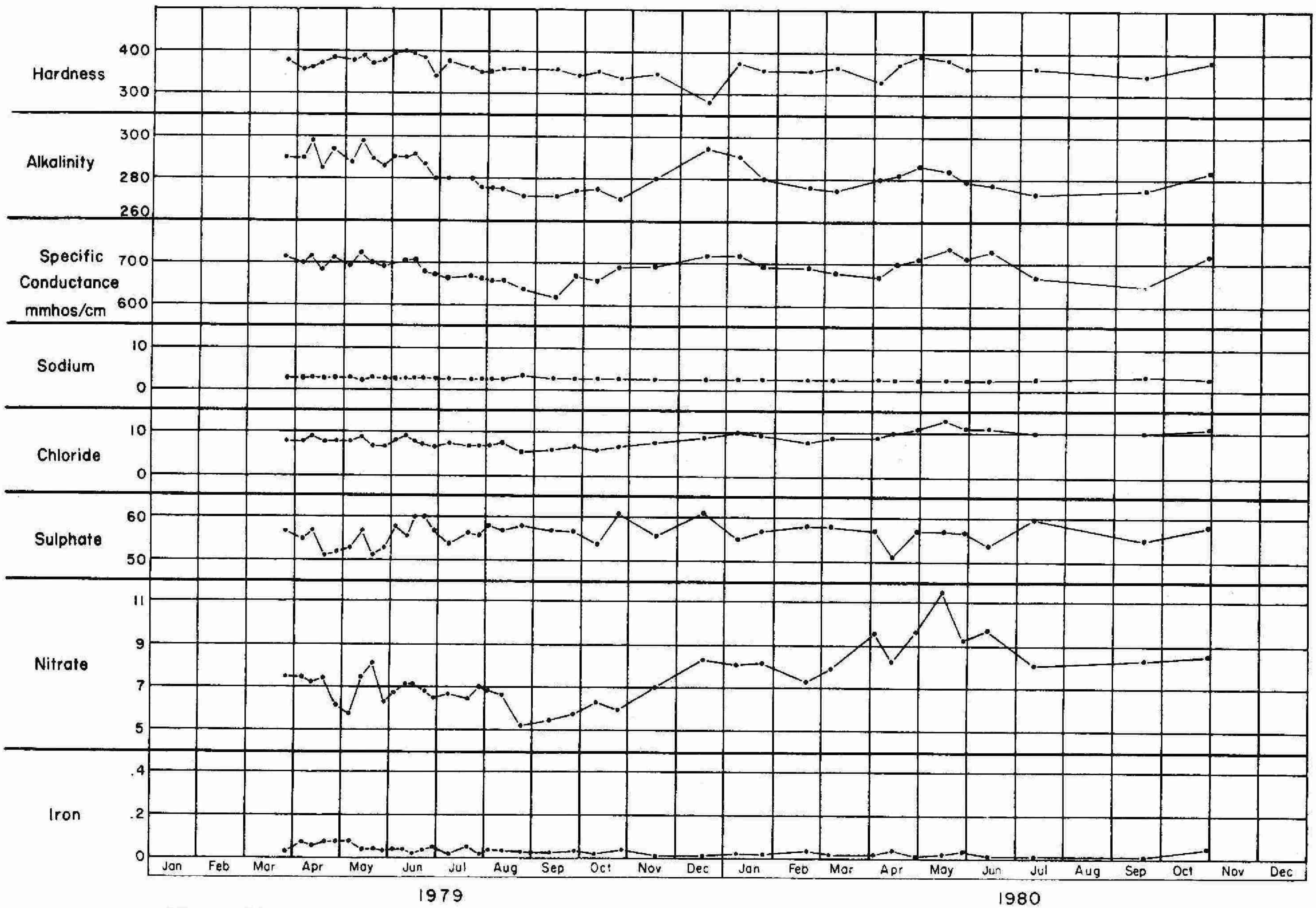

Figure A.1 - Well No. 1 Ground Water Quality Graph

(All units in mg/L unless noted)

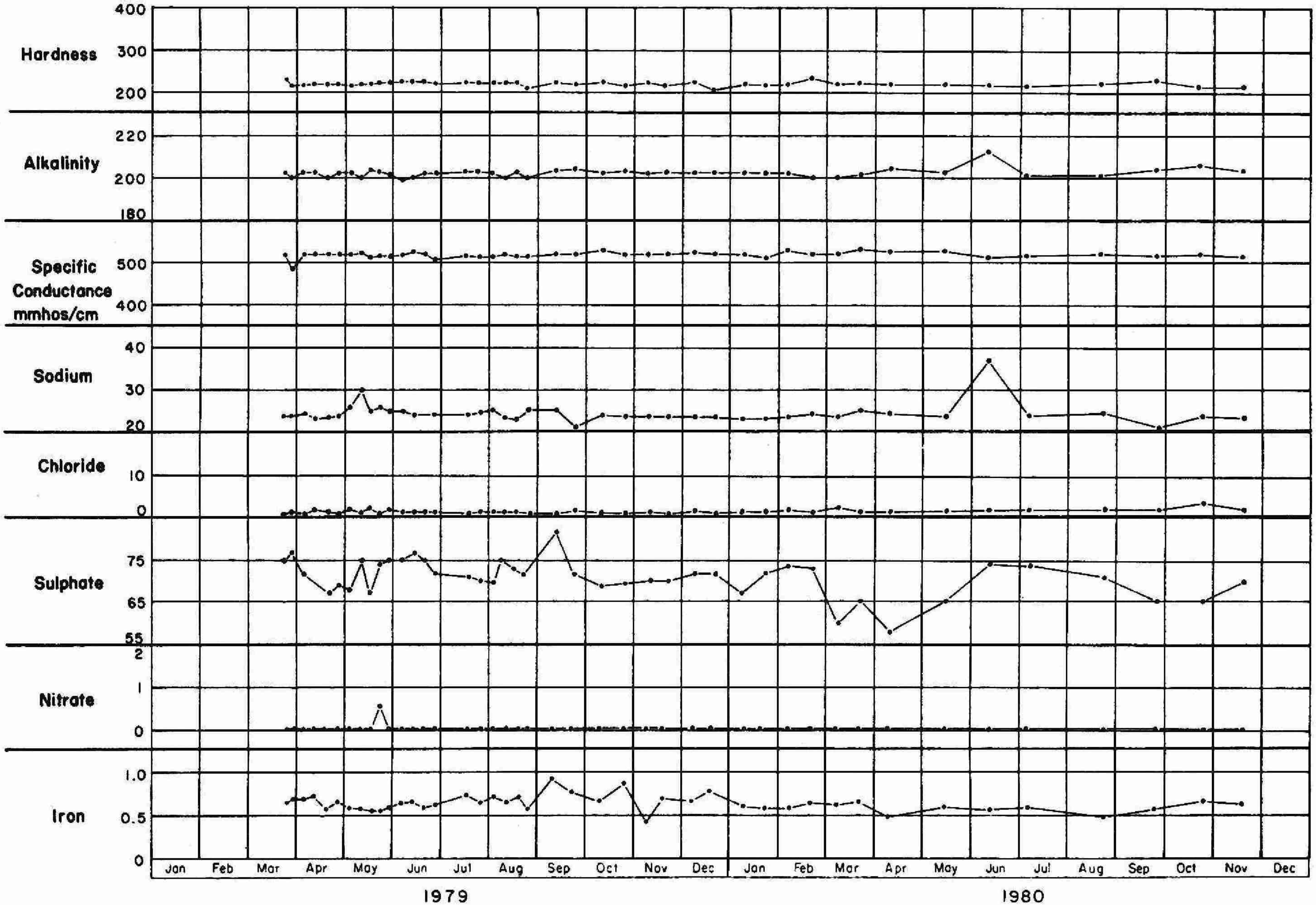

Figure A.2 - Well No. 2 Ground Water Quality Graph

(All units in mg/L unless noted)

Figure A.3 – Well No. 3 Ground Water Quality Graph

(All units in mg/L unless noted)

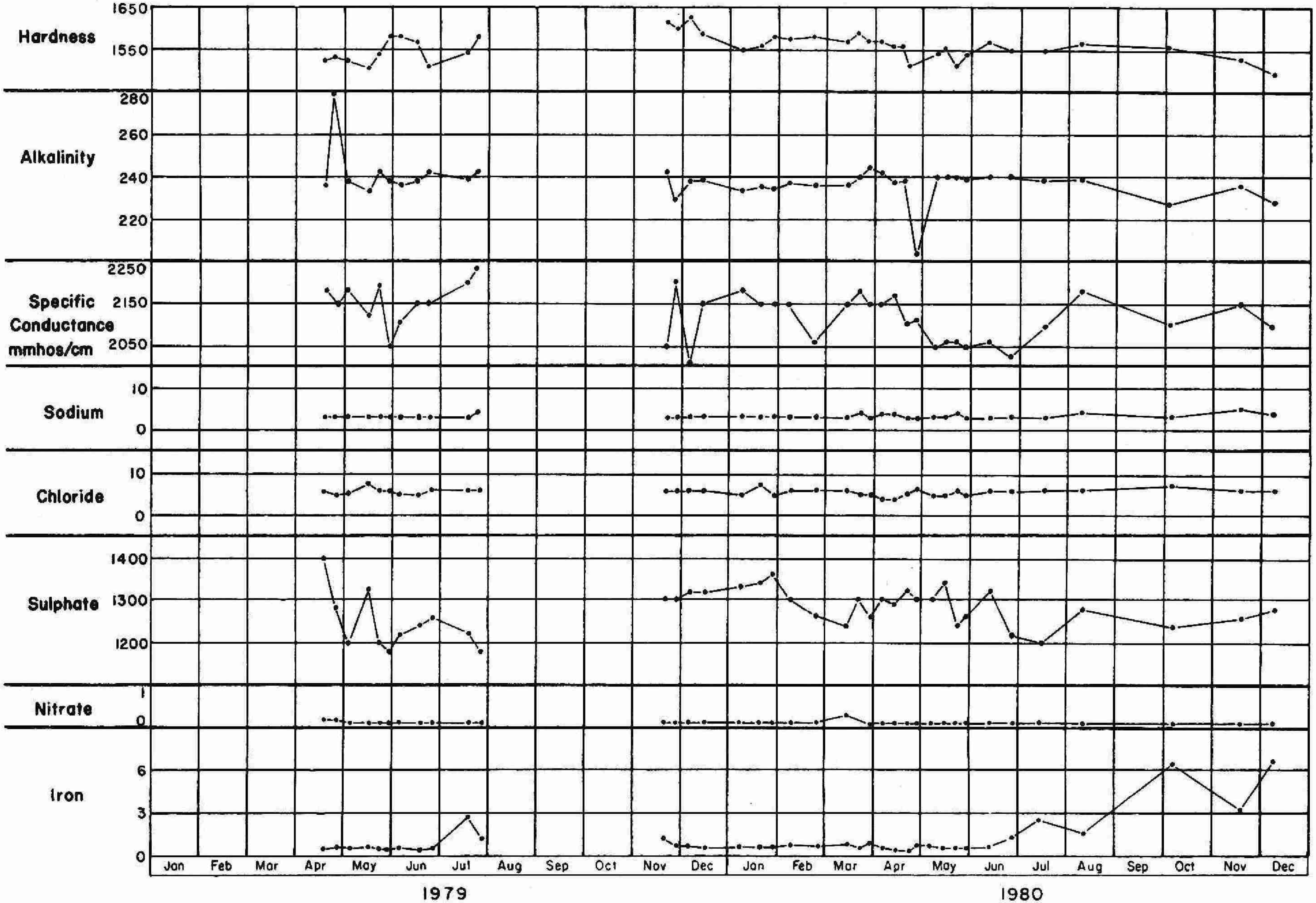

Figure A.4 - Well No. 4 Ground Water Quality Graph

(All units in mg/L unless noted)

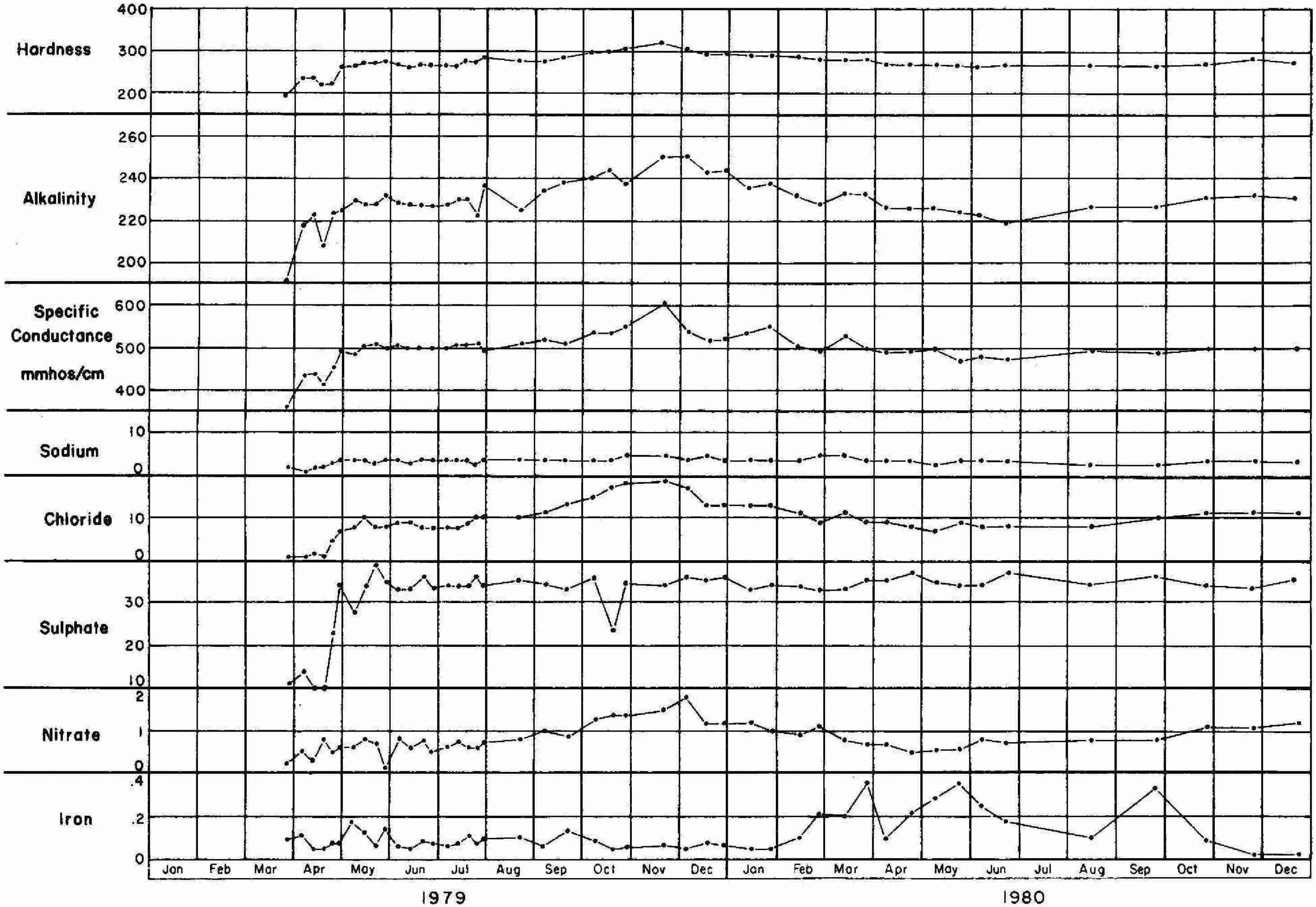

Figure A.5 – Well No. 5 Ground Water Quality Graph

(All units in mg/L unless noted)

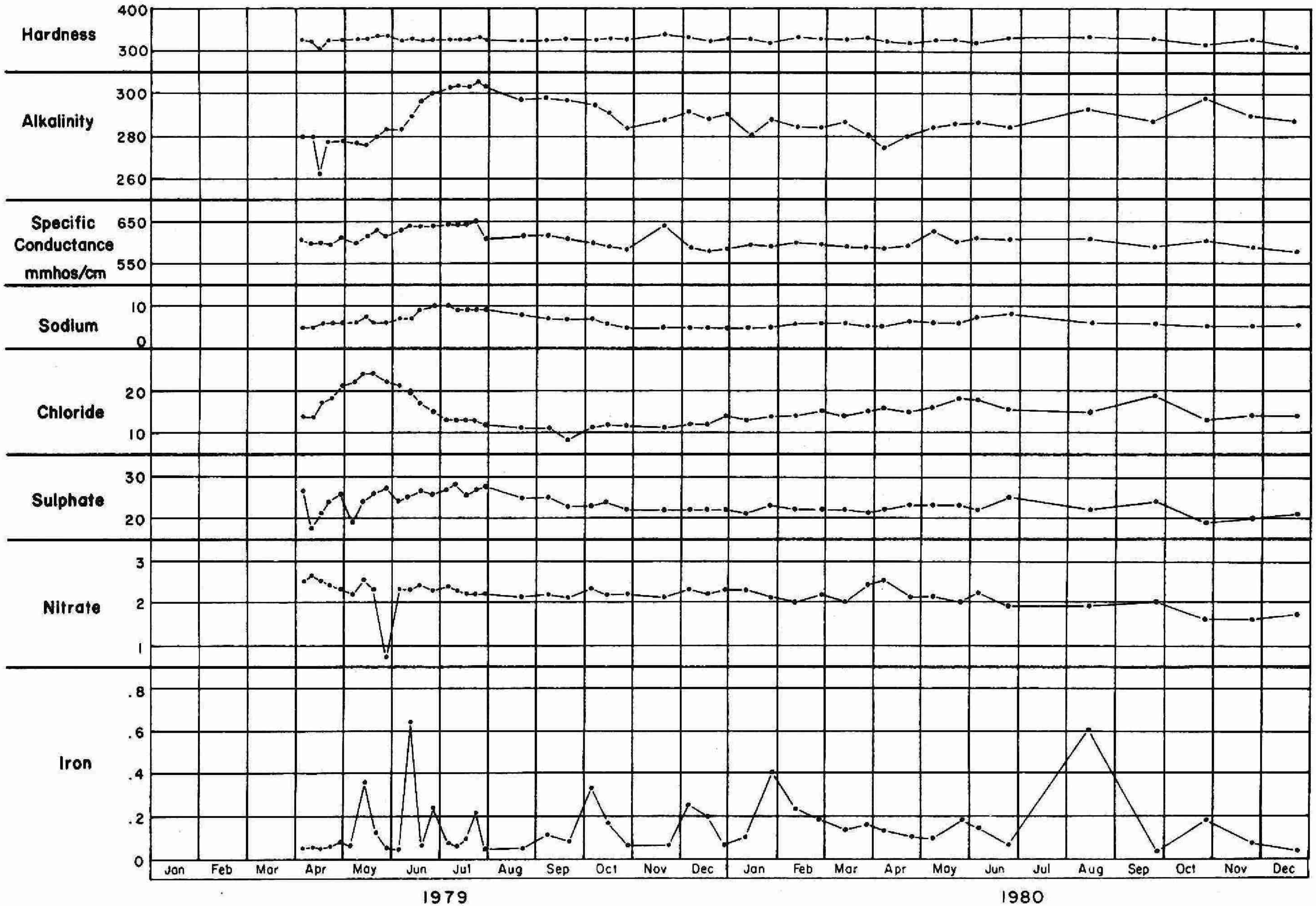

Figure A.6 – Well No. 6 Ground Water Quality Graph

(All units in mg/L unless noted)

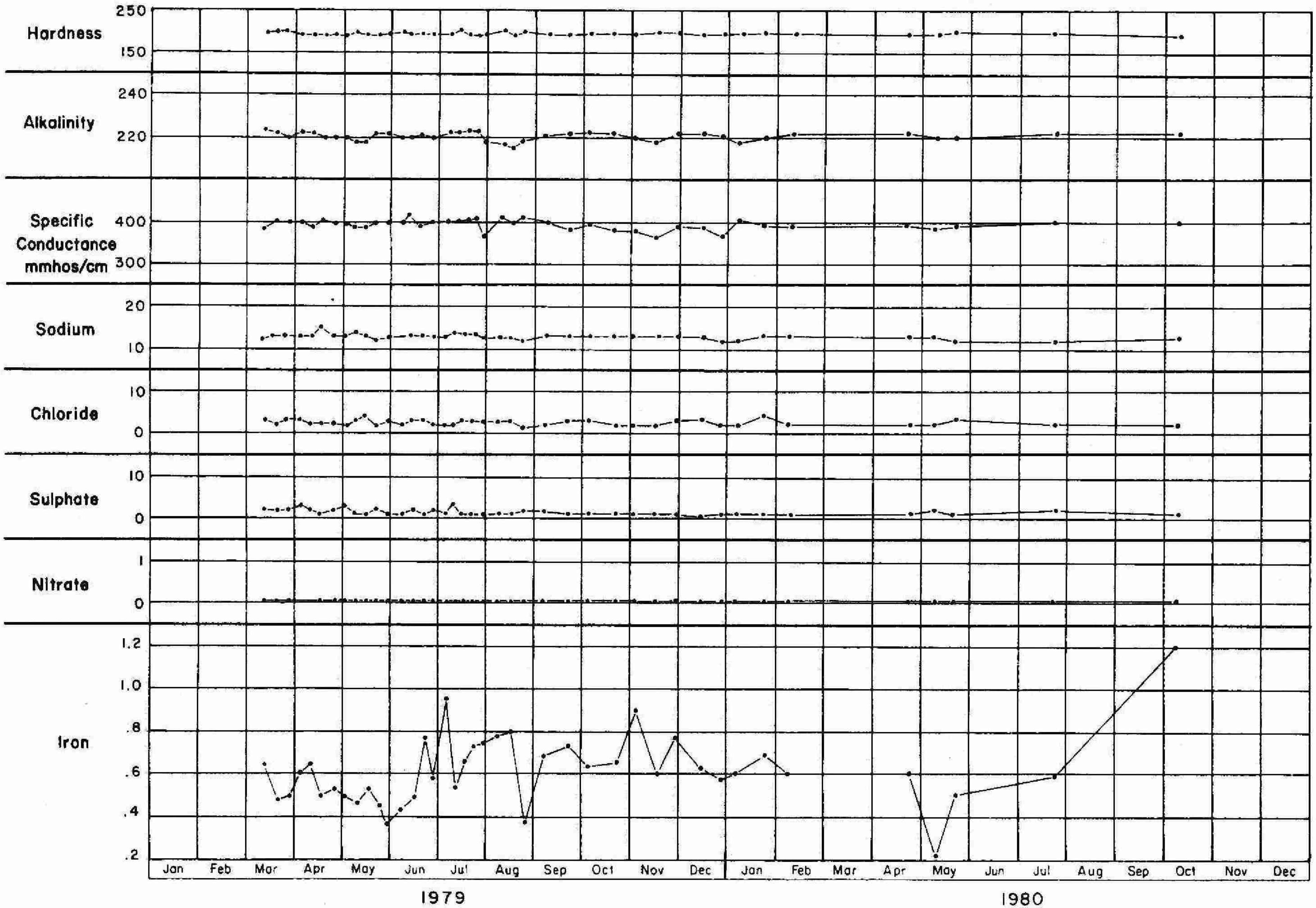

Figure A.7 – Well No. 7 Ground Water Quality Graph

(All units in mg/L unless noted)

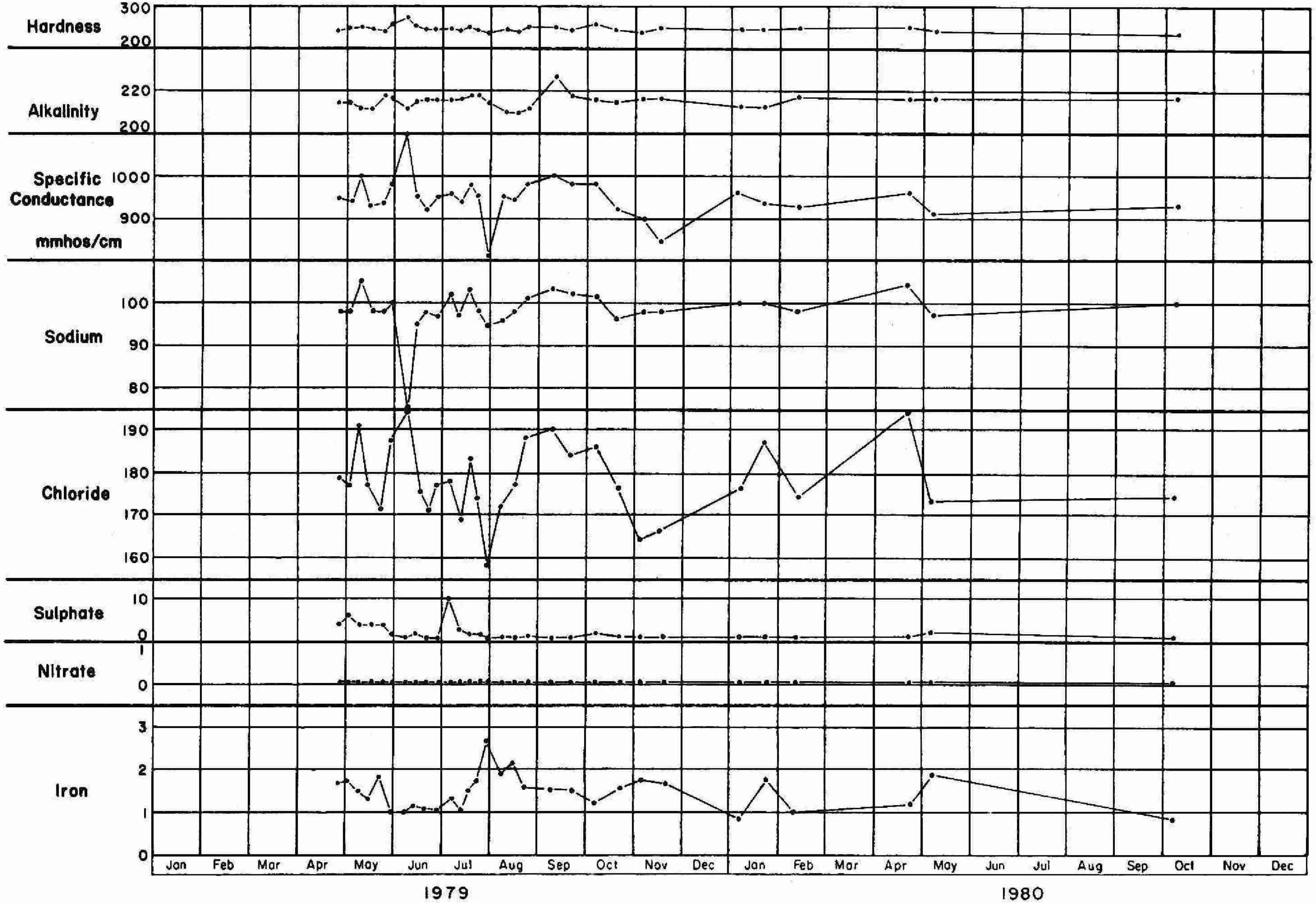

Figure A.8 – Well No. 8 Ground Water Quality Graph

(All units in mg/L unless noted)

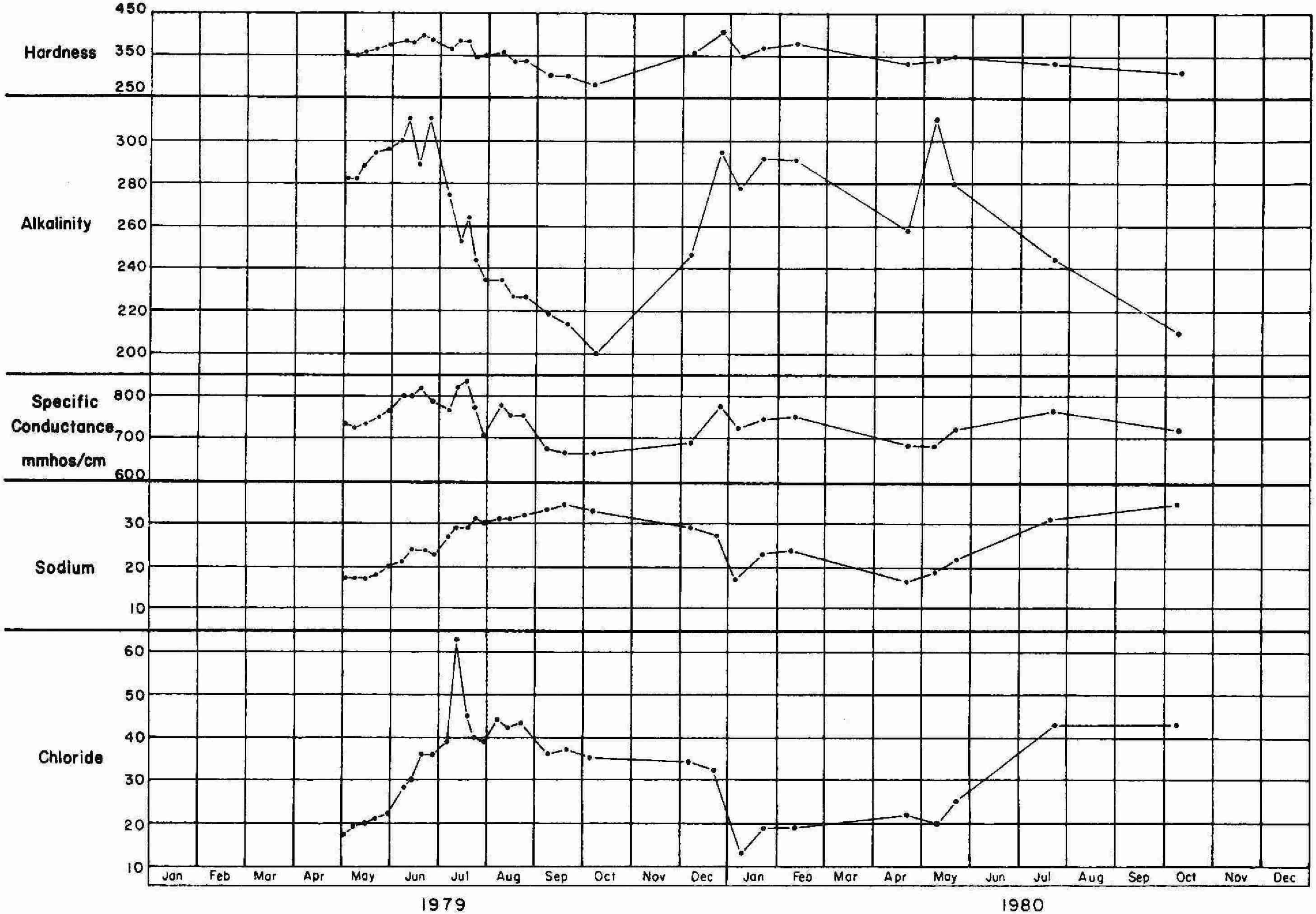

Figure A.9a - Well No. 9 Ground Water Quality Graph

(All units in mg/L unless noted)

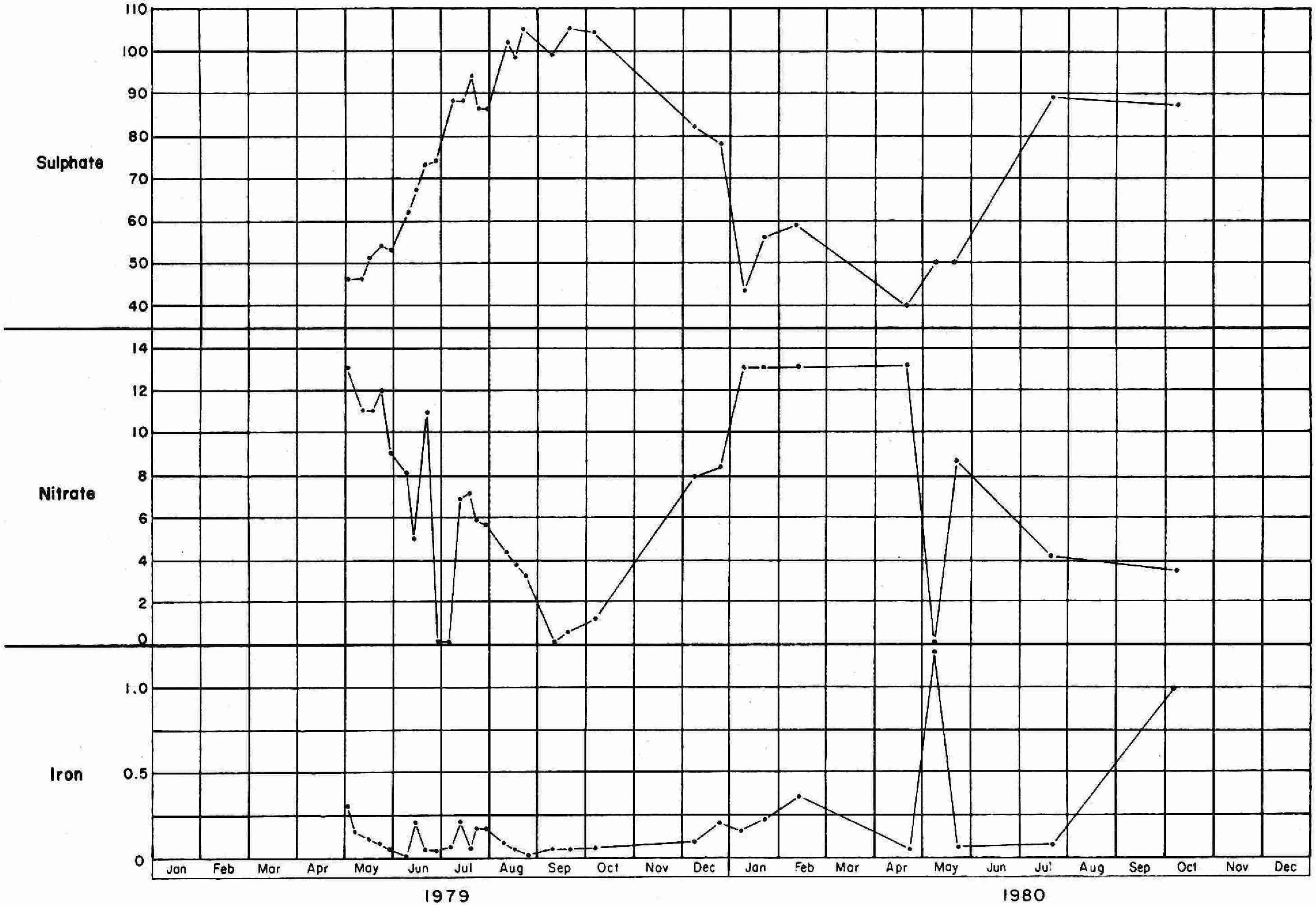

Figure A.9b – Well No. 9 Ground Water Quality Graph

(All units in mg/L)

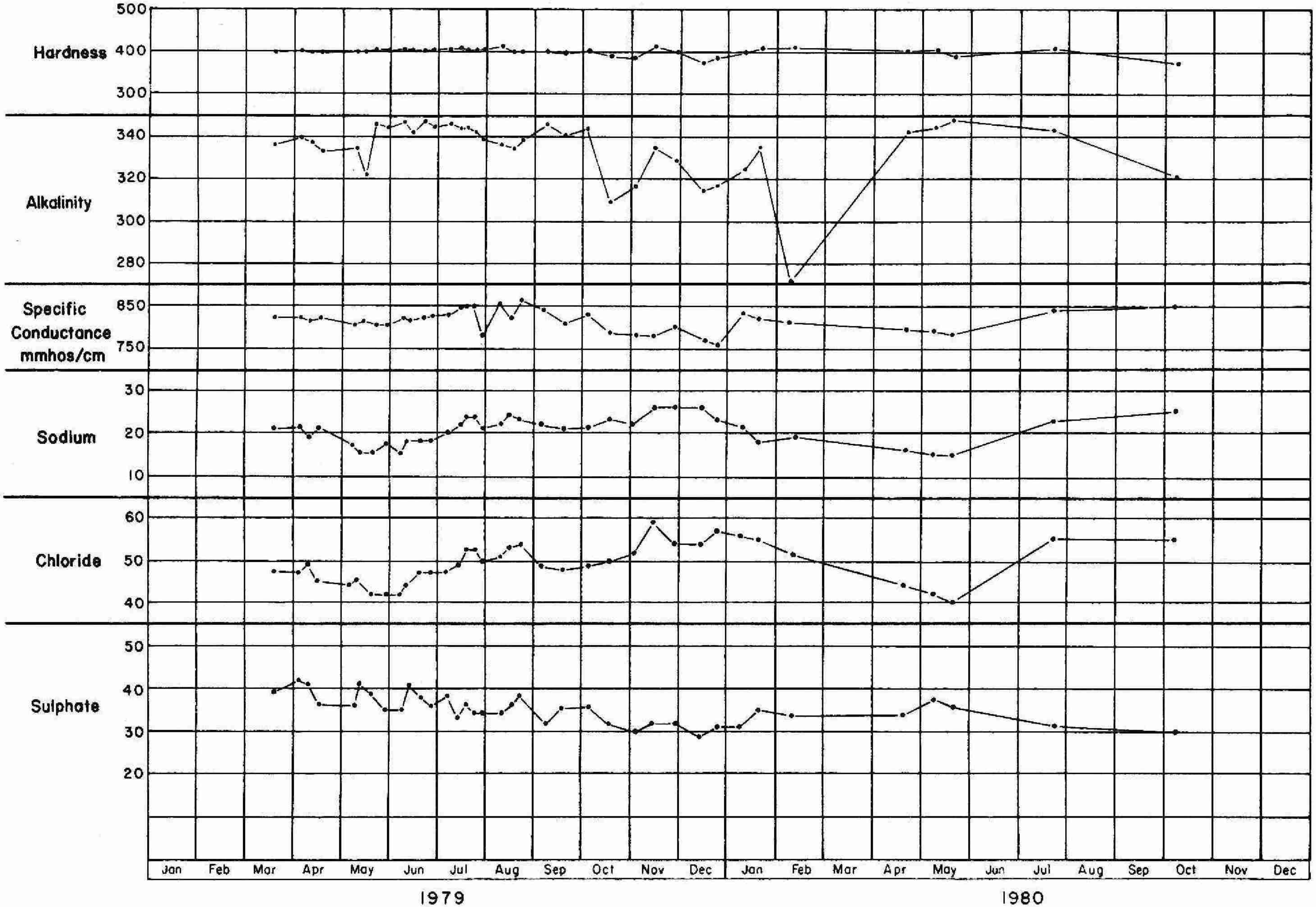

Figure A.10a – Well No. 10 Ground Water Quality Graph

(All units in mg/L unless noted)

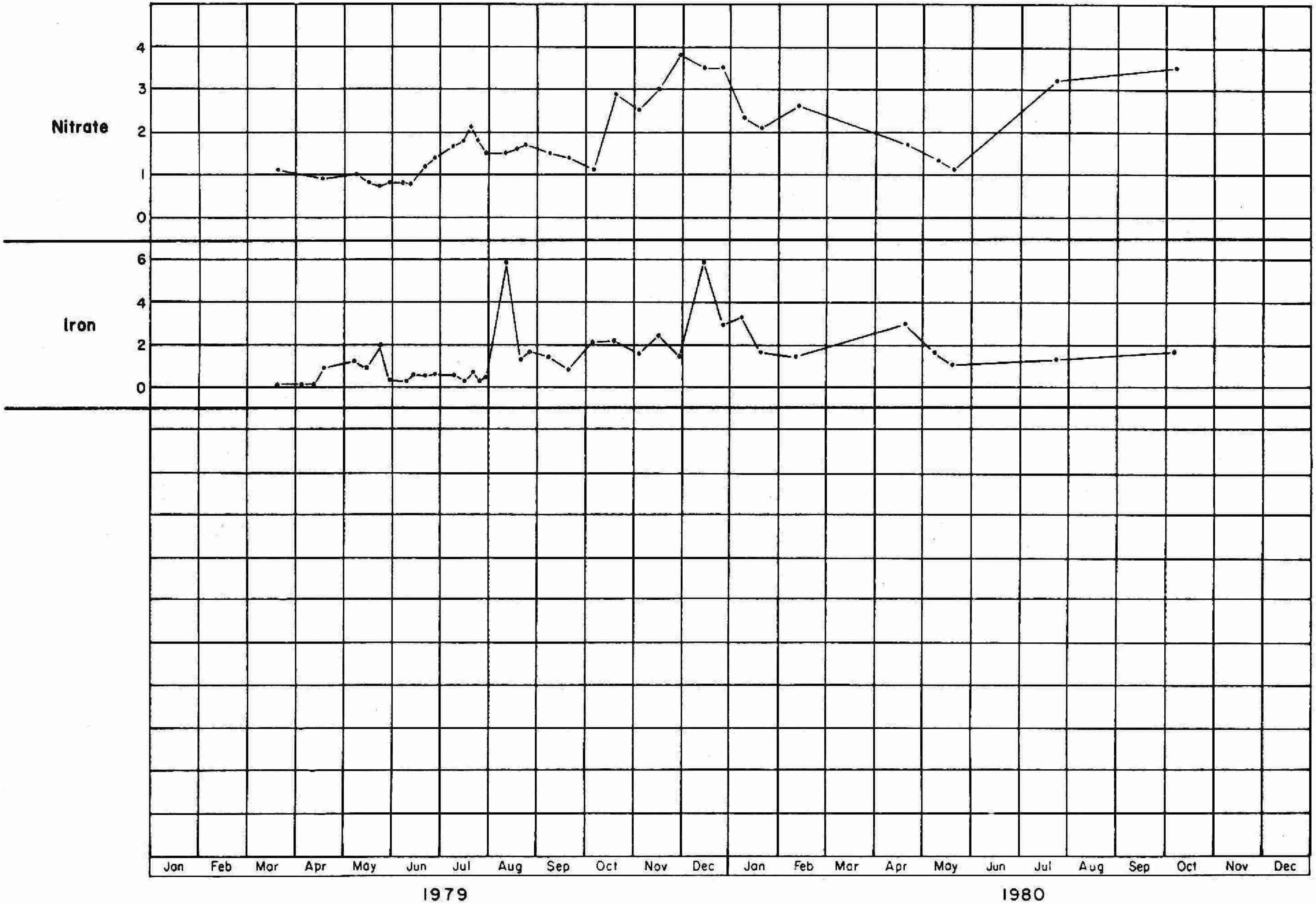

Figure A.10b — Well No. 10 Ground Water Quality Graph

(All units in mg/L)

Appendix B

Chemical Composition of Ground Water

- Statistical Summary -

APPENDIX B

Chemical Composition of Ground Water
- Statistical Summary -

Parameter	Well No.	Minimum	Maximum	Mean	Range	Standard Deviation	Coefficient of Variation	Number of Analyses
Sodium mg/L	1	2	4	3	2	0.3	9.6	39
	2	21	37	25	16	2.4	9.7	43
	3	3	7	4	4	0.6	15.6	43
	4	3	5	3	2	0.5	15.3	37
	5	1	5	4	4	0.8	22.6	48
	6	5	10	6	5	1.5	23.5	46
	7	12	15	13	3	0.6	4.9	40
	8	75	105	98	30	5.1	5.2	30
	9	16	34	26	18	6.0	23.4	30
	10	15	26	20	11	3.5	17.5	37
Calcium mg/L	1	96	119	108	23	6.3	5.8	38
	2	41	47	45	6	1.3	3.0	44
	3	61	87	70	26	5.2	7.4	43
	4	548	625	583	77	16.0	2.7	37
	5	70	114	93	44	12.4	13.3	48
	6	99	135	117	36	12.9	11.0	46
	7	38	82	76	44	9.6	12.5	41
	8	55	111	96	56	10.7	11.2	30
	9	83	164	139	81	16.3	11.7	30
	10	110	168	157	58	11.9	7.6	37

APPENDIX B (cont'd)

Parameter	Well No.	Minimum	Maximum	Mean	Range	Standard Deviation	Coefficient of Variation	Number of Analyses
Magnesium mg/L	1	21	27	25	6	1.3	5.3	39
	2	25	30	27	5	1.0	3.6	44
	3	19	35	27	16	2.7	10.0	43
	4	1	42	24	41	7.9	33.1	36
	5	4	26	17	22	4.4	25.6	27
	6	8	19	15	11	2.4	15.9	26
	7	20	24	21	4	2.3	10.8	3
	8	21	24	23	3	2.1	9.4	2
	9	8	24	15	16	8.3	56.8	3
	10	16	27	21	11	5.7	27.5	3
Alkalinity mg/L	1	270	298	282	28	7.7	2.7	39
	2	199	212	202	13	2.1	1.0	44
	3	233	256	248	23	4.8	1.9	43
	4	204	280	237	76	9.7	4.1	37
	5	172	250	228	78	12.8	5.6	48
	6	261	306	287	45	9.4	3.3	46
	7	215	223	221	8	1.9	0.9	41
	8	210	227	215	17	3.0	1.4	30
	9	200	310	264	110	33.2	12.6	30
	10	271	348	334	77	15.1	4.5	37

APPENDIX B (cont'd)

Parameter	Well No.	Minimum	Maximum	Mean	Range	Standard Deviation	Coefficient of Variation	Number of Analyses
Hardness mg/L	1	278	401	367	123	21.5	5.8	38
	2	211	234	221	23	4.8	2.2	44
	3	254	299	288	45	8.1	2.8	43
	4	1488	1628	1554	140	30.1	1.9	37
	5	189	322	271	133	24.5	9.0	48
	6	301	342	327	41	7.2	2.2	46
	7	193	206	197	13	2.6	1.3	41
	8	232	278	246	46	8.2	3.3	30
	9	289	409	353	120	29.2	8.3	30
	10	371	419	400	48	10.3	2.6	37
Chloride mg/L	1	6	13	9	7	1.7	19.8	39
	2	1	4	1	3	0.6	51.6	44
	3	4	8	6	4	1.0	17.0	43
	4	4	8	6	4	0.8	13.8	37
	5	1	18	10	17	3.8	40.2	48
	6	8	24	15	16	3.6	23.8	46
	7	1	4	3	3	0.6	24.9	41
	8	158	195	178	37	8.9	5.0	30
	9	13	63	32	50	11.4	35.5	30
	10	40	59	49	19	4.9	10.0	37
Sulphate mg/L	1	51	62	56	11	2.6	4.7	39
	2	58	82	71	24	4.4	6.3	43
	3	21	47	38	26	4.6	12.1	43
	4	1180	1400	1275	220	52.3	4.1	37
	5	9	39	32	30	7.4	23.1	48
	6	18	28	23	10	2.5	10.7	46
	7	1	3	1	2	0.6	44.0	41
	8	1	10	2	9	1.7	95.7	30
	9	40	105	74	65	21.4	29.0	30
	10	29	42	35	13	3.4	9.5	37

APPENDIX B (cont'd)

Parameter	Well No.	Minimum	Maximum	Mean	Range	Standard Deviation	Coefficient of Variation	Number of Analyses
Nitrate mg/L	1	5.2	11.5	7.5	6.3	1.3	17.6	39
	2	0.1	0.6	0.1	0.5	0.08	67.6	43
	3	0.1	0.1	0.1	0	0	0	43
	4	0.1	0.3	0.1	0.2	0.04	36.0	36
	5	0.1	1.8	0.8	1.7	0.3	41.8	48
	6	0.7	2.6	2.1	1.9	0.3	15.9	46
	7	0.1	0.1	0.1	0	0	0	39
	8	0.1	0.1	0.1	0	0	0	30
	9	0.1	13.0	6.8	12.9	4.5	66.1	30
	10	0.7	3.8	1.8	3.1	0.9	49.8	35
Iron mg/L	1	0.01	0.08	0.03	0.07	0.02	58.3	39
	2	0.44	0.92	0.6	0.48	0.09	14.5	44
	3	1.10	4.80	2.5	3.70	0.80	32.0	43
	4	0.35	6.60	1.2	6.25	1.46	126.3	30
	5	0.02	0.36	0.1	0.34	0.09	73.3	48
	6	0.04	0.65	0.2	0.61	0.14	90.7	46
	7	0.22	1.20	0.6	0.98	0.17	27.8	41
	8	0.82	2.66	1.5	1.84	0.42	28.5	30
	9	0.02	1.20	0.2	1.18	0.26	147.8	30
	10	0.05	5.90	1.4	5.85	1.39	96.1	37
Lab pH	1	7.2	7.6	7.4	0.4	0.09	1.2	39
	2	7.5	7.9	7.7	0.4	0.4	1.2	44
	3	7.4	8.2	7.7	0.8	0.18	2.4	43
	4	7.2	7.9	7.5	0.7	0.14	1.9	37
	5	7.4	8.0	7.7	0.6	0.15	1.9	48
	6	7.2	8.1	7.5	0.9	0.18	2.4	46
	7	7.5	8.3	8.0	0.8	0.16	2.0	41
	8	7.5	8.0	7.7	0.5	0.13	1.7	30
	9	7.0	8.1	7.5	1.1	0.24	3.2	30
	10	6.1	8.1	7.4	2.0	0.30	4.1	37

APPENDIX B (cont'd)

Parameter	Well No.	Minimum	Maximum	Mean	Range	Standard Deviation	Coefficient of Variation	Number of Analyses
Specific Conductance mmhos/cm at 25°C.	1	620	738	689	118	26.5	3.9	39
	2	483	530	518	47	7.4	1.4	44
	3	458	560	512	102	19.5	3.8	43
	4	2000	2230	2127	230	55.8	2.6	37
	5	352	605	496	253	43.1	8.7	48
	6	570	650	607	80	21.2	3.5	46
	7	365	410	396	45	9.6	2.4	41
	8	810	1200	949	390	62.3	6.6	30
	9	670	830	744	160	46.6	6.3	30
	10	760	860	813	100	25.4	3.1	37
Potassium mg/L	1	0.5	2.2	1.0	1.7	0.4	36.3	38
	2	1.6	1.7	1.6	0.1	0.1	4.7	3
	3	0.8	2.0	1.0	1.2	0.2	19.2	30
	4	1.9	2.2	2.0	0.3	0.1	4.0	28
	5	1.0	1.4	1.2	0.4	0.1	6.8	42
	6	1.3	13.9	4.4	12.6	4.1	92.2	41
	7	1.4	1.5	1.5	0.1	0.1	3.4	4
	8	5.5	6.1	5.8	0.6	0.4	6.0	4
	9	2.5	10.0	7.8	7.5	2.7	34.6	6
	10	6.9	12.0	10.5	5.1	1.8	17.4	6

Appendix C

Variability Plots by Parameter

Means, Maximums, Minimums and Coefficients of Variation

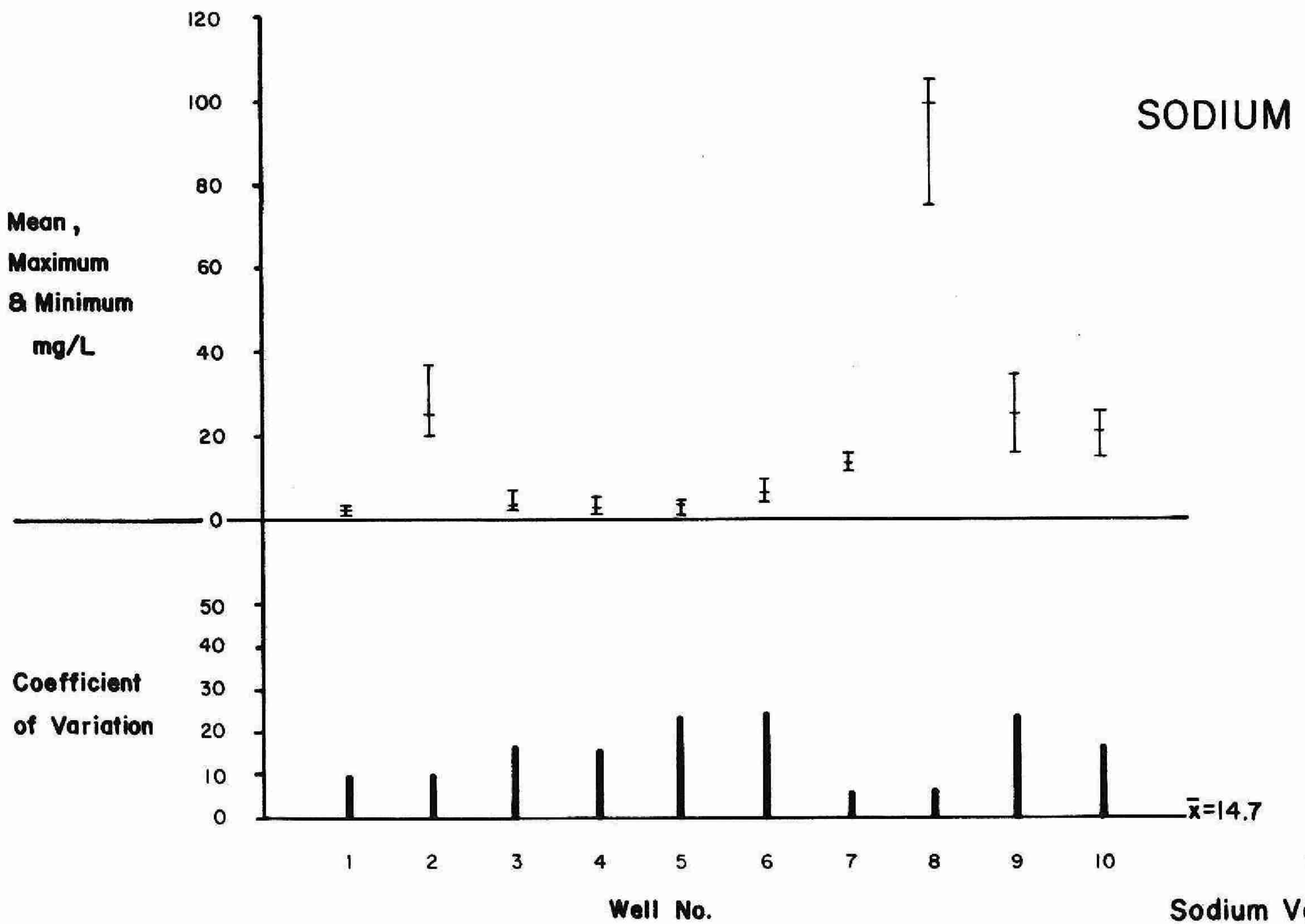

Figure C.1 –
Sodium Variability Plots

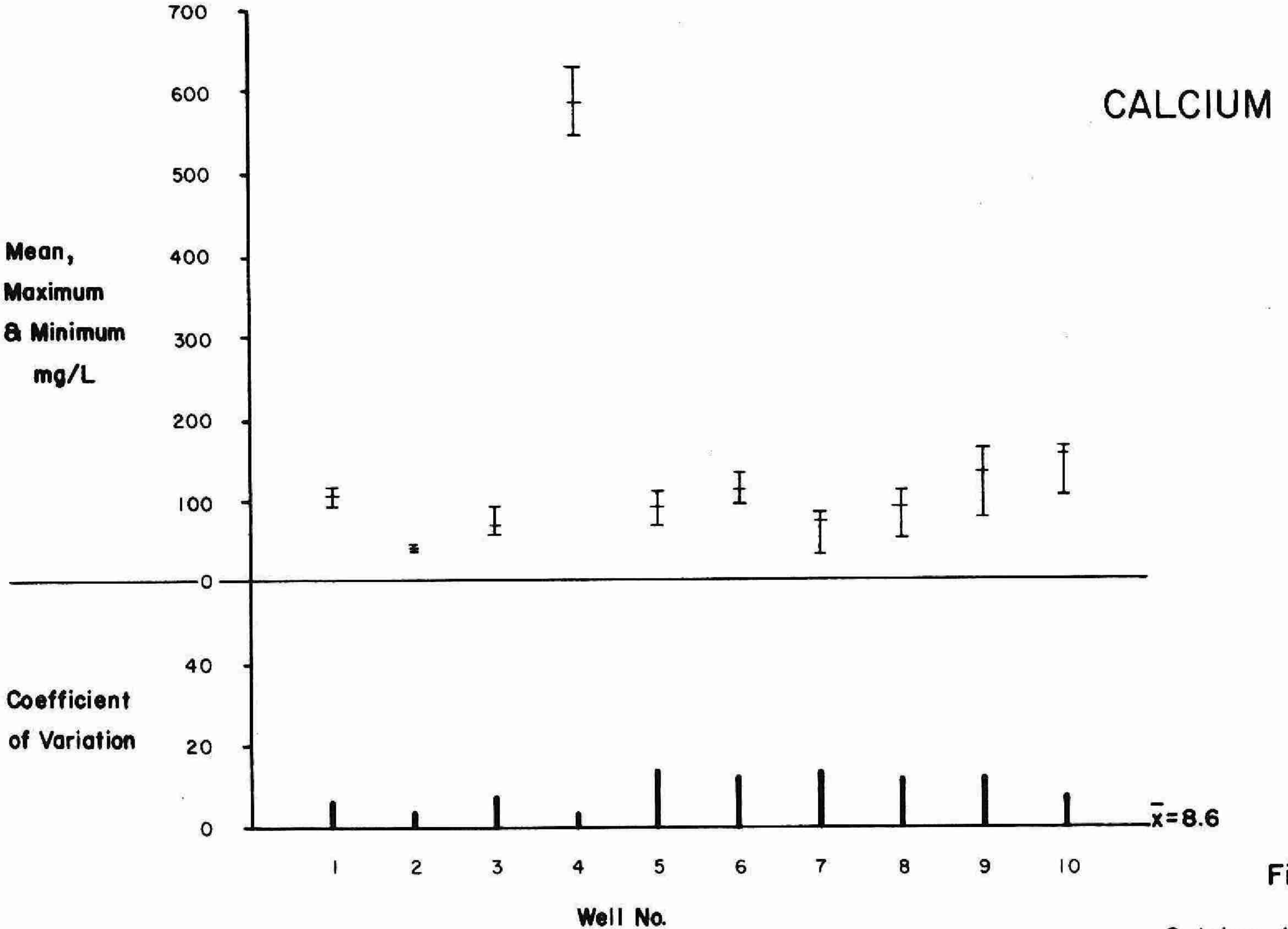

Figure C.2 -

Calcium Variability Plots

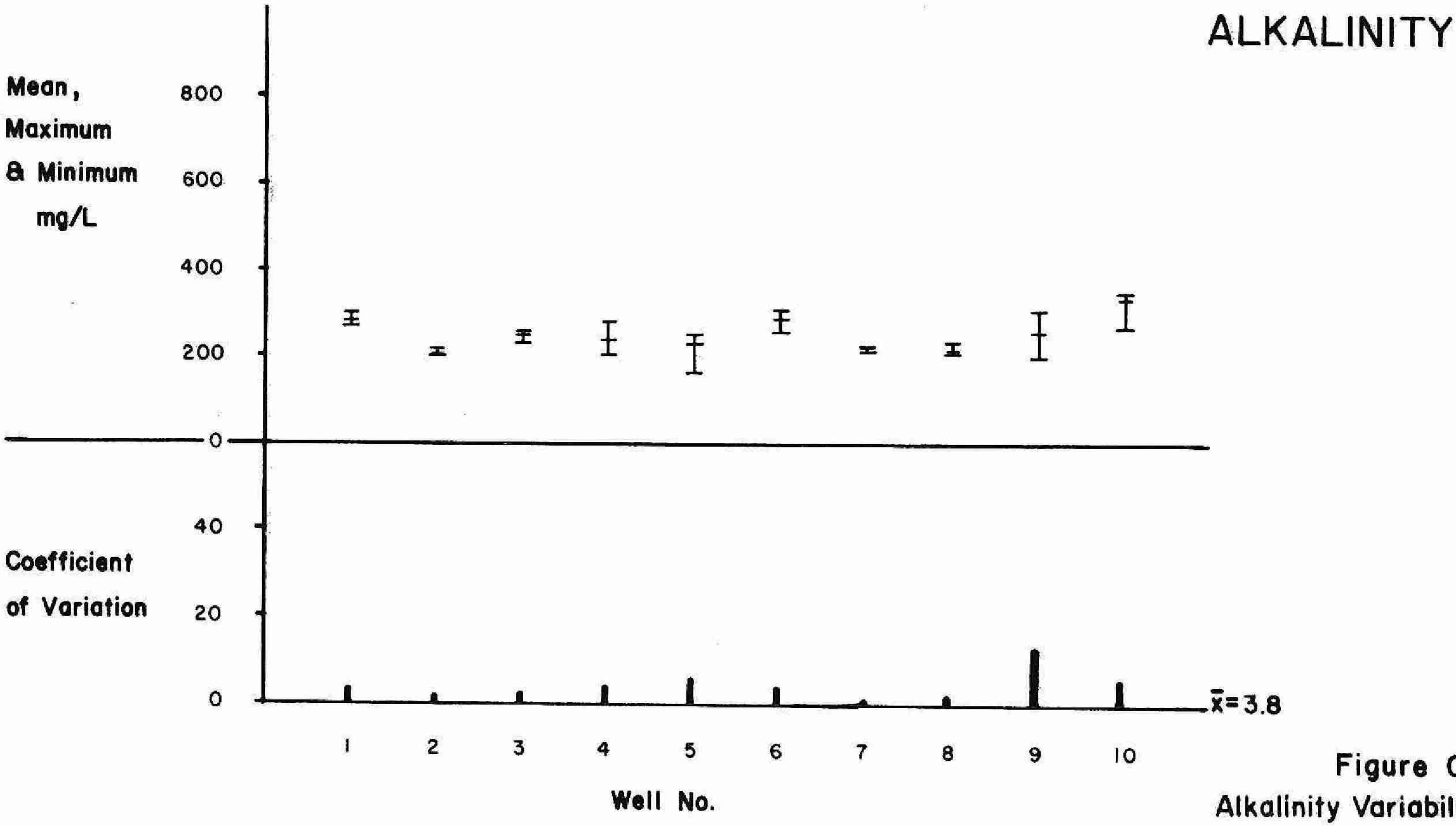

Figure C.3 – Alkalinity Variability Plots

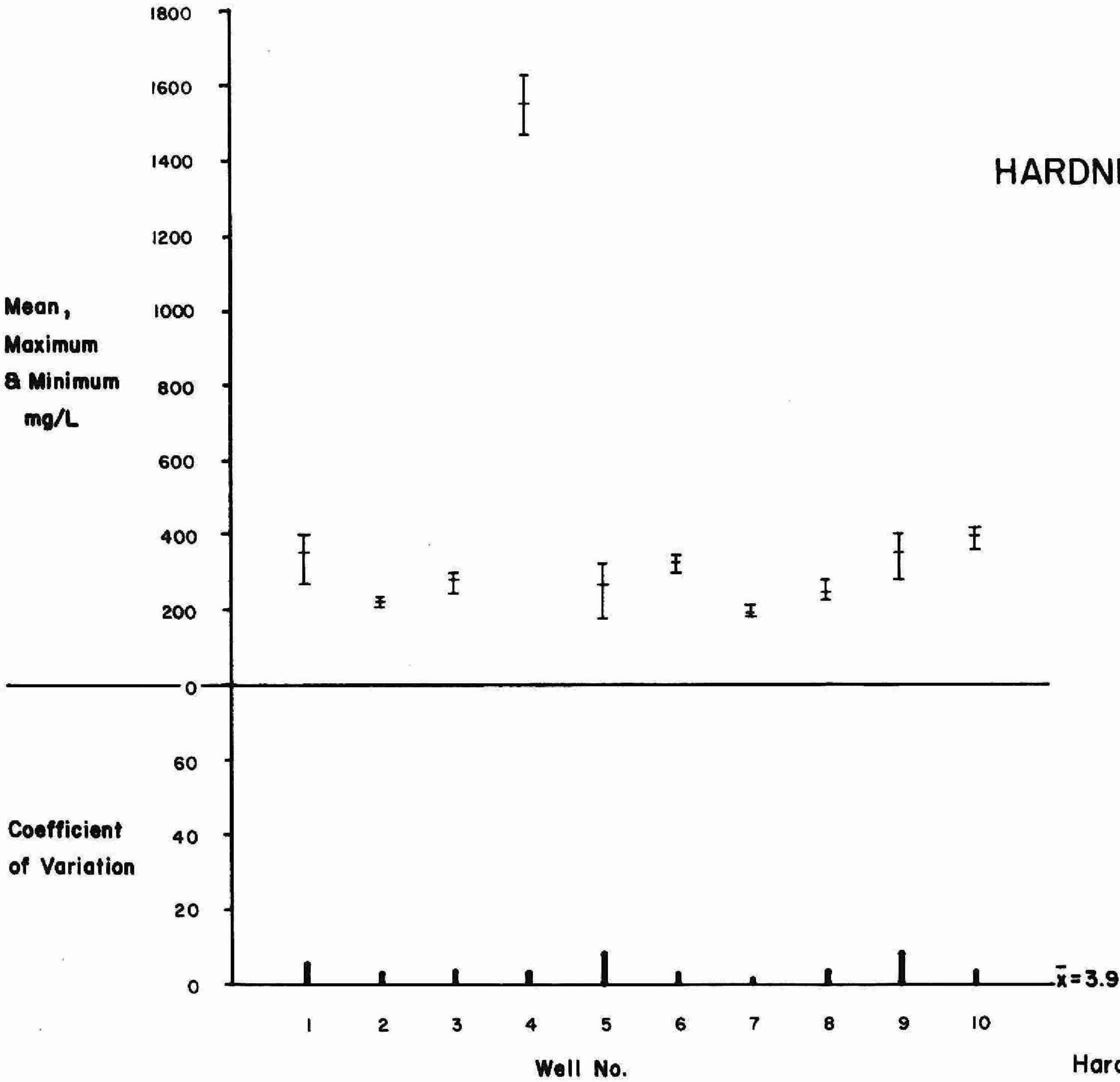

Figure C.4 -
Hardness Variability Plots

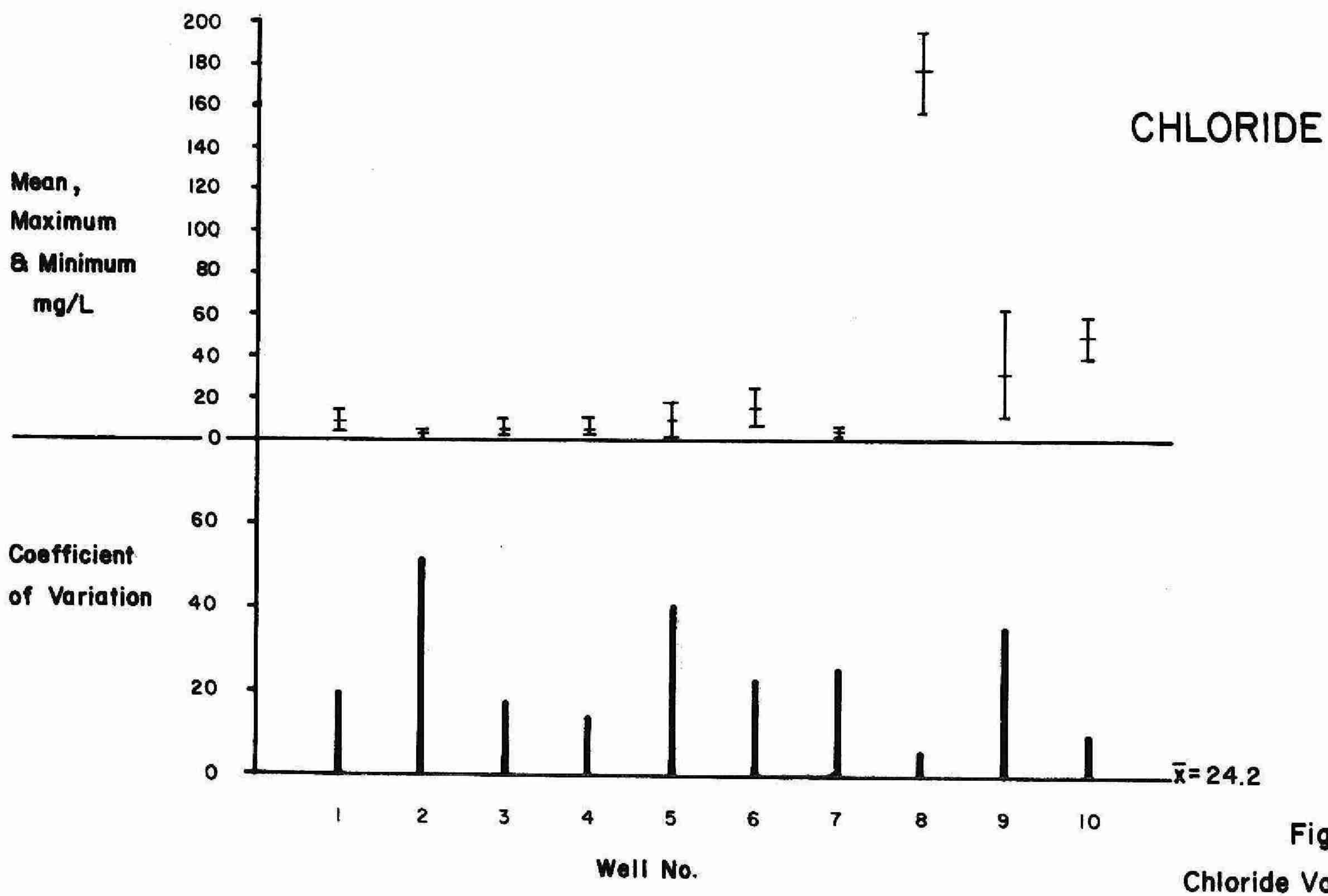

Figure C.5 – Chloride Variability Plots

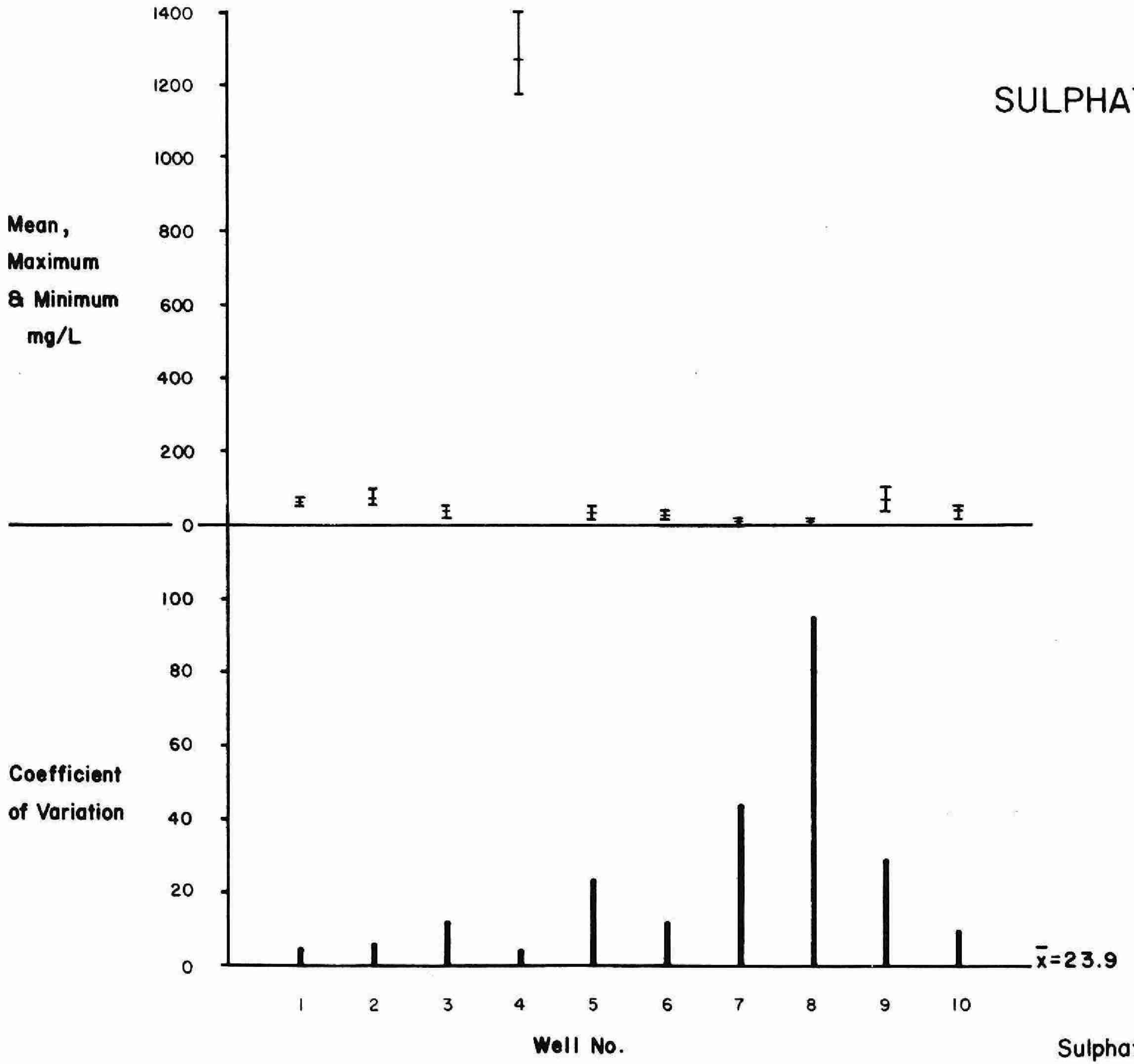

Figure C.6 –
Sulphate Variability Plots

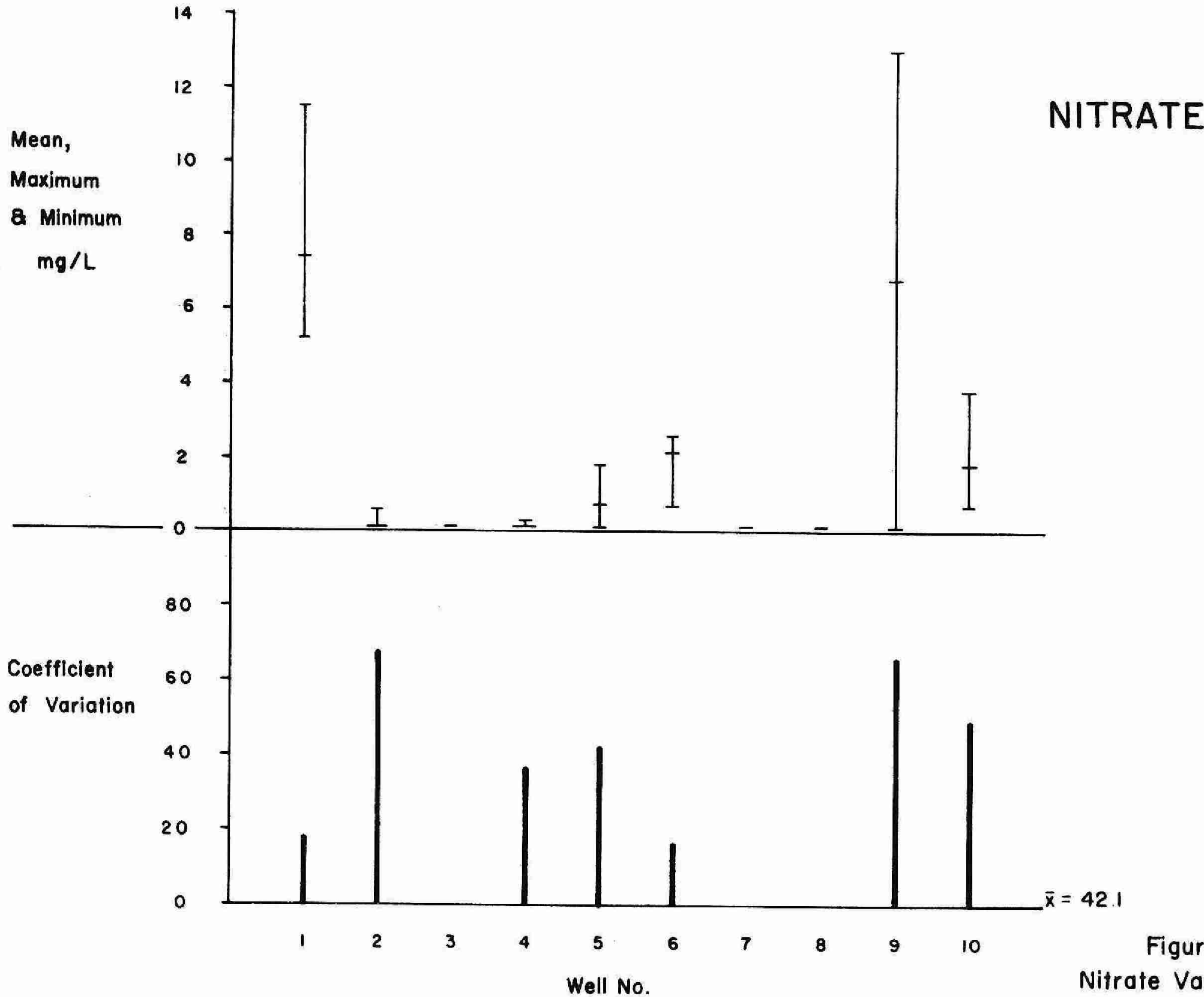

Figure C.7 –
Nitrate Variability Plots

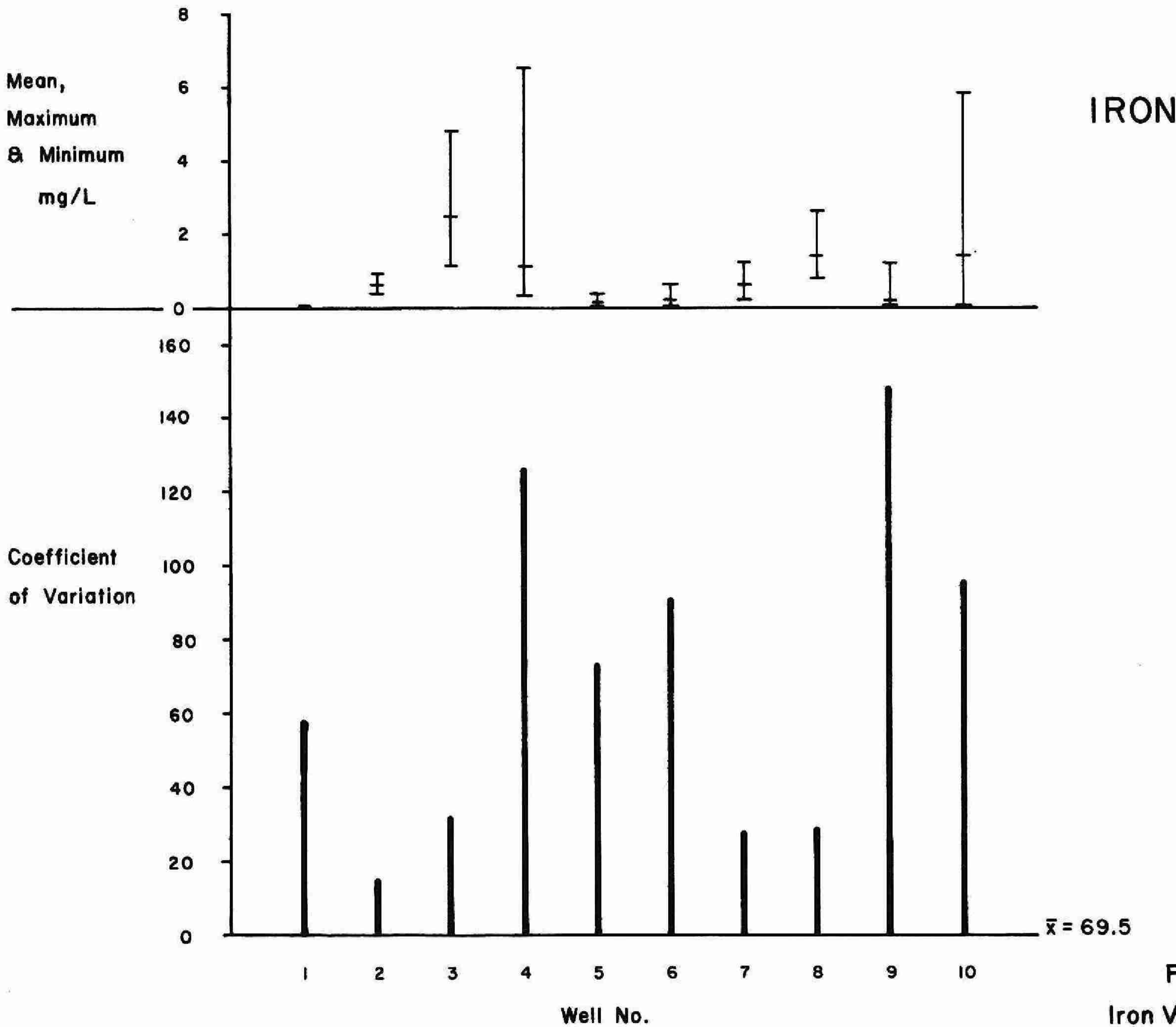

Figure C.8 –
Iron Variability Plots

pH

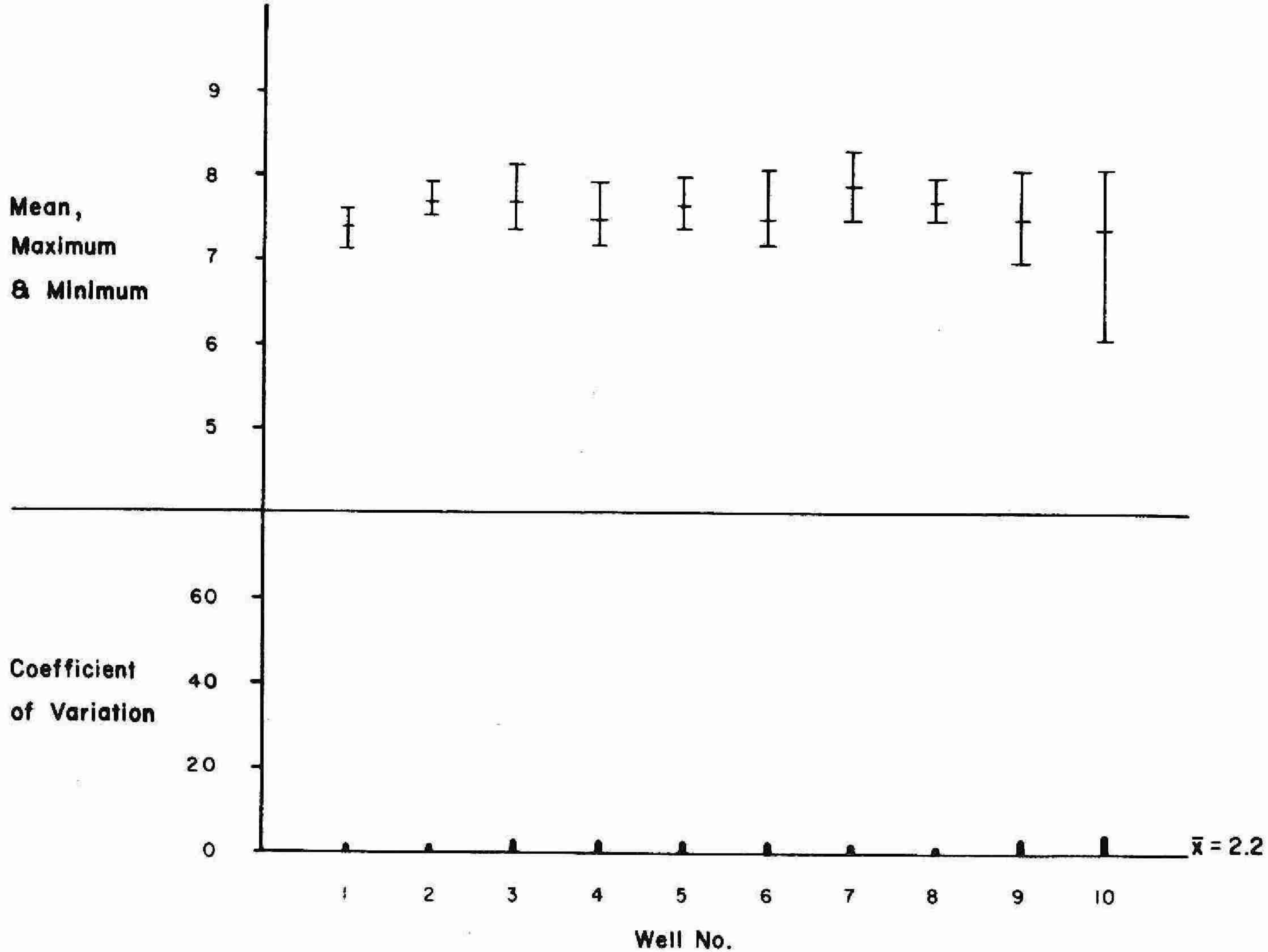

Figure C.9 –
pH Variability Plots

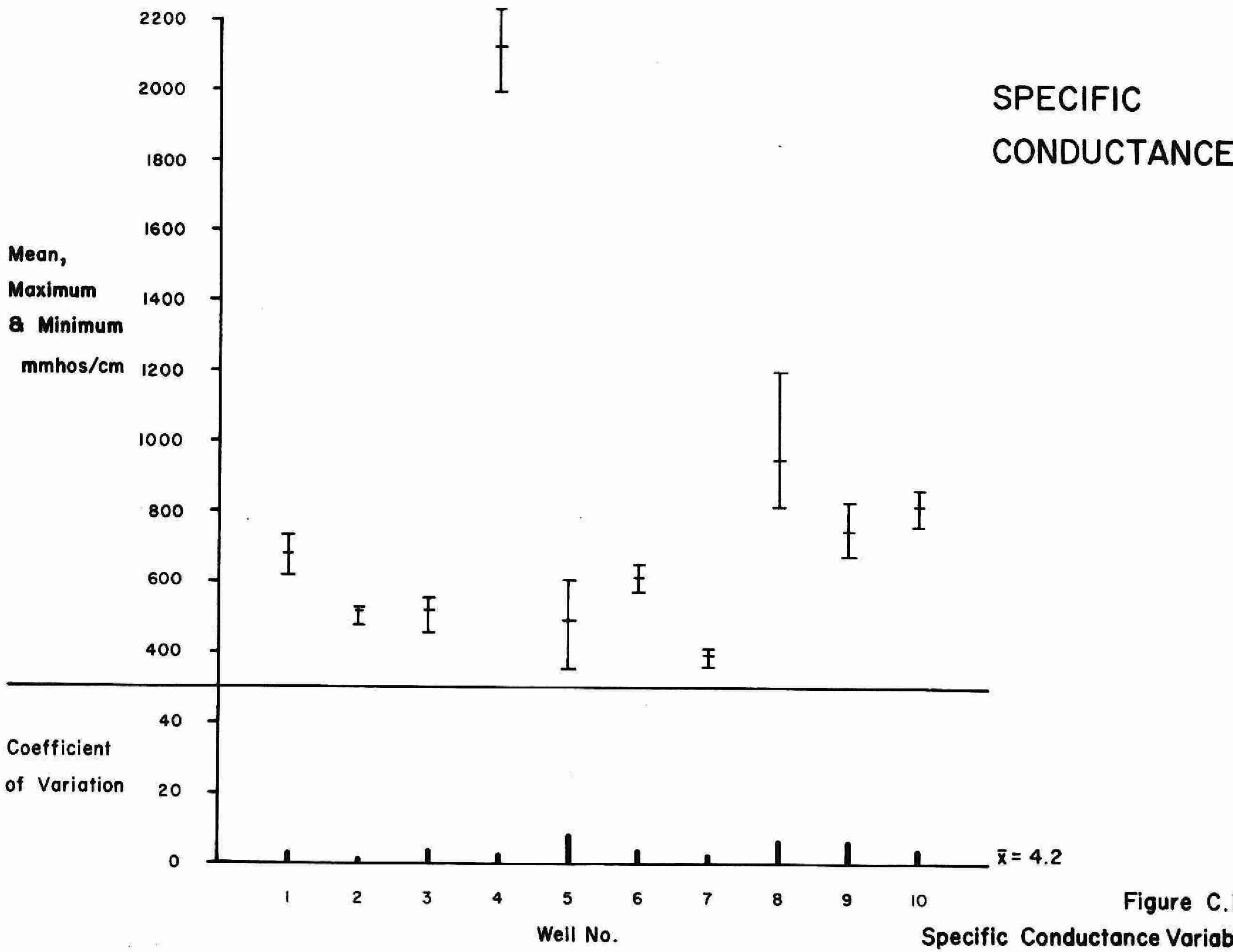

Figure C.10 – Specific Conductance Variability Plots

Appendix D

Trace Metals and Pollutant Indicators

APPENDIX D

Trace Metals and Pollutant Indicators - mg/L
February - March 1980

Well No.	Se	As	SiO_2	CN	Mn	Cu	Zn	Ba	Cd	Cr	Pb	Ag
1	<.001	.001	4.7	<.01	<.02	.11	.20	.02	<.005	<.02	<.03	<.005
2	<.001	.001	5.5	<.01	<.02	<.01	.53	.02	<.005	<.02	<.03	<.005
3	<.001	.002	7.9	<.01	.05	.04	.23	.22	<.005	<.02	<.03	<.005
4	<.001	<.001	3.2	<.01	<.02	.17	<.1	.10	<.005	<.02	<.03	.01
5	<.001	.001	5.6	<.01	<.02	.04	.16	.02	<.005	<.02	<.03	<.005
6	<.001	.001	7.1	<.01	<.02	.14	.12	.06	<.005	<.02	<.03	<.005
7	<.001	<.001	12.5	<.01	.05	<.01	.08	.10	.010	<.02	<.03	<.005
8	<.001	<.001	.8	<.01	.15	<.01	.04	1.2	.008	<.02	<.03	<.005
9	<.001	.002	7.3	<.01	<.02	.11	.30	.06	.010	<.02	<.03	<.005
10	<.001	.002	7.0	<.01	.03	.03	.29	.16	.083	<.02	<.03	<.005

Well No.	F	Nitrogen Cycle				DOC	MBAS
		Free Ammonia	Total Kjeldahl	Nitrite	Nitrate		
1	0.10	.005	0.13	.001	7.3	1.0	<0.1
2	1.59	.180	0.23	.001	<.01	0.8	<0.1
3	0.2	<.10	.4	.01	.1	0.8	<0.1
4	0.5	<.10	.20	<.01	.5	1.4	<0.1
5	0.1	<.10	.20	.01	1.1	0.7	<0.1
6	0.1	<.10	.20	<.01	2.2	1.2	<0.1
7*	0.17	.3	.6	<.01	.1	0.7	<0.1
8*	0.30	1.0	1.2	<.01	.1	0.8	<0.1
9*	0.18	<.10	.2	<.01	3.5	1.2	<0.1
10*	0.11	<.10	.2	<.01	3.5	1.2	<0.1

*Note: Sampling for pollutant indicators completed in Oct. 1980

- Underscored values equal or exceed MOE recommended drinking water quality criteria (MOE, 1978)